limHaloPT

one-loop halo model for LIM

Version 1.0.0

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Generated by Doxygen 1.9.2

1 Summary

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Welcom to limHaloPT, a numerical package for computing the clustering and shot-noise contributions to the power spectrum of line intensity/temprature fluctuations within halo-model framework. The current version of the code, is limited to real-space, and redshift-space distortions will be included in the next release.

The extended halo model of line intensity power spectrum implemented in limHaloPT, combines the predictions of EFTofLSS for halo power spectrum with the standard halo model to account for the nonlinear evolution of matter fluctuations and the nonlinear biasing relation between line intensity fluctuations and the underlying dark matter distribution in 2-halo term. Furthermore, the model includes the effect of large bulk velocities (Infrared Resummation) in the 2-halo term. The deviations from Poisson shot noise on large scales are also computed within the halo model.

This package is released together with the following publication, `arXiv:2111.03717`, where the prediction of the model are tested against new suite of simulated intensity (brightness temprature) maps of CO and [CII] lines. The mesheded fileds from MithraLIMSims will be publically avilable on `MithraLIMSims`. The code to analyse the simulated maps is an extension of the toolskit used in analysin Hidden-Valley simulations, and is publically avialble on `LIM Analysis`. As discussed in the manuscript above, the packages to compute the theory predictions and creating the simulated intensity maps can be straightforwardly extended to compute the power spectrum signal of other emission lines (emitted from star-froming galaxies), beside CO and [CII].

The source code of this package is publically avaialbel on GitHub at `limHaloPT`.

1.0.1 Dependencies

The limHaloPT package calls various functions from `CLASS` Boltzman solver, including the matter power spectrum and transfer functions, growth factor etc. Therefore, you need to first download and compile CLASS code, and place the "libclass.a" file in the " CLASS/lib/" folder. Furtehrmore, the loop calculations are performed with direct numerical integration, using routines of `CUBA` library. Furthermore, the code heavily uses functions of `GSL` scientific library. Therfore, make sure that the two libraries are correctly linked to limHaloPT by making necassary modifcations to the makefile (placed in Source directory) of limHaloPT package.

1.0.2 Compilation and Usage

- To compile, type: make

- To run, type: ./limHaloPT

If you modified the code, you need to first do "make clean" before doing "make". Depending on what quantities you want to calculate, you can modify the main() function in main.c module (as marked in the code). As examples, I have included the calls to two functions to compute the clustering and shot noise contributions.

1.0.3 Attribution

You can use this package freely, provided that in your publication you cite the following paper: Moradinezhad, Nikakhtar, Keating, Castorina: `arXiv:2111.03717`. Furthermore, since limHaloPT relies on CLASS Boltzman code, you should also cite at least this paper `arxiv:1104.2933` as required by CLASS developers.

1.0.4 License

2 Data Structure Index

2.1 Data Structures

Here are the data structures with brief descriptions:

3 File Index

3.1 File List

Here is a list of all files with brief descriptions:

4 Data Structure Documentation

4.1 Class_Cosmology_Struct Struct Reference

Structure to store cosmology structure from CLASS code.

```
#include <Global_Structs.h>
```

Data Fields

- struct precision pr
- struct background ba
- struct thermo th
- struct perturbs pt
- struct transfers tr
- struct primordial pm
- struct spectra sp
- struct nonlinear nl
- struct lensing le
- struct output op
- ErrorMsg errmsg

4.1.1 Detailed Description

Structure to store cosmology structure from CLASS code.

4.1.2 Field Documentation

4.1.2.1 ba `struct background ba`

4.1.2.2 errmsg `ErrorMsg errmsg`

4.1.2.3 le `struct lensing le`

4.1.2.4 nl `struct nonlinear nl`

4.1.2.5 op `struct output op`

4.1.2.6 pm `struct primordial pm`

4.1.2.7 pr `struct precision pr`

4.1.2.8 pt `struct perturbs pt`

4.1.2.9 sp `struct spectra sp`

4.1.2.10 th `struct thermo th`

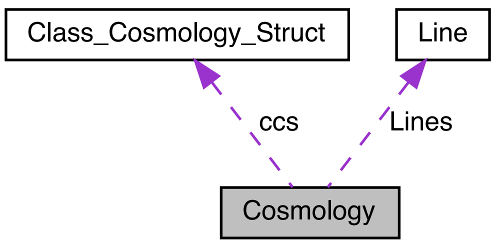
4.1.2.11 tr `struct transfers tr`

4.2 Cosmology Struct Reference

Structure that holds varioud quantities that need to be evaluated for a given choice of cosmological paramteres.

```
#include <Global_Structs.h>
```

Collaboration diagram for Cosmology:



Data Fields

- struct Class_Cosmology_Struct ccs
- struct Line ** Lines
- int NLines
- long mode_nu
- double cosmo_pars [6]

4.2.1 Detailed Description

Structure that holds varioud quantities that need to be evaluated for a given choice of cosmological paramteres.

This includes, the Class_Cosmology_Struct (initialized in cosmology.c), and Line Structure (initialized in line_ingredients.c).

4.2.2 Field Documentation

4.2.2.1 ccs `struct Class_Cosmology_Struct ccs`

4.2.2.2 cosmo_pars `double cosmo_pars[6]`

4.2.2.3 Lines `struct Line** Lines`

4.2.2.4 mode_nu `long mode_nu`

4.2.2.5 NLines `int NLines`

4.3 globals Struct Reference

A global structure including the values of cosmological parmaeters, 2d interpolator of SFR, and names of various files.

```
#include <Global_Structs.h>
```

Data Fields

- double H0
- double c
- double As
- double logAs
- double ns
- double h
- double Omega_cdm
- double Omega_b
- double Omega_r
- double Omega_lambda
- double Omega_g
- double Omega_nu
- double b1
- double sigFOG0
- long Npars
- double z_i
- double rho
- double mass
- double kp
- double ng
- double volume
- double kf
- double h_m
- double M_min
- double M_max
- double z_max
- char project_home [FILENAME_MAX]
- char output_dir [FILENAME_MAX]
- char data_dir [FILENAME_MAX]
- char data_priors [FILENAME_MAX]
- double PS_kmin
- double PS_kmax
- char SFR_filename [FILENAME_MAX]
- char Planck_Fisher_filename [FILENAME_MAX]
- gsl_interp_accel ∗ logM_accel_ptr
- gsl_interp_accel ∗ z_accel_ptr
- gsl_spline2d ∗ logSFR_spline2d_ptr

4.3.1 Detailed Description

A global structure including the values of cosmological parmaeters, 2d interpolator of SFR, and names of various files.

4.3.2 Field Documentation

4.3.2.1 As `double As`

4.3.2.2 b1 `double b1`

4.3.2.3 c `double c`

4.3.2.4 data_dir `char data_dir[FILENAME_MAX]`

4.3.2.5 data_priors `char data_priors[FILENAME_MAX]`

4.3.2.6 h `double h`

4.3.2.7 H0 `double H0`

4.3.2.8 h_m `double h_m`

4.3.2.9 kf `double kf`

4.3.2.10 kp
`double kp`

4.3.2.11 logAs
`double logAs`

4.3.2.12 logM_accel_ptr
`gsl_interp_accel* logM_accel_ptr`

4.3.2.13 logSFR_spline2d_ptr
`gsl_spline2d* logSFR_spline2d_ptr`

4.3.2.14 M_max
`double M_max`

4.3.2.15 M_min
`double M_min`

4.3.2.16 mass
`double mass`

4.3.2.17 ng
`double ng`

4.3.2.18 Npars
`long Npars`

4.3.2.19 ns
`double ns`

4.3.2.20 Omega_b
`double Omega_b`

4.3.2.21 Omega_cdm `double Omega_cdm`

4.3.2.22 Omega_g `double Omega_g`

4.3.2.23 Omega_lambda `double Omega_lambda`

4.3.2.24 Omega_nu `double Omega_nu`

4.3.2.25 Omega_r `double Omega_r`

4.3.2.26 output_dir `char output_dir[FILENAME_MAX]`

4.3.2.27 Planck_Fisher_filename `char Planck_Fisher_filename[FILENAME_MAX]`

4.3.2.28 project_home `char project_home[FILENAME_MAX]`

4.3.2.29 PS_kmax `double PS_kmax`

4.3.2.30 PS_kmin `double PS_kmin`

4.3.2.31 rho `double rho`

4.3.2.32 SFR_filename `char SFR_filename[FILENAME_MAX]`

4.3.2.33 sigFOG0 `double sigFOG0`

4.3.2.34 volume `double volume`

4.3.2.35 z_accel_ptr `gsl_interp_accel* z_accel_ptr`

4.3.2.36 z_i `double z_i`

4.3.2.37 z_max `double z_max`

4.4 integrand_parameters Struct Reference

A structure passed to the integrators to hold the parameters fixed in the integration.

```
#include <header.h>
```

Data Fields

- double p1
- double p2
- double p3
- double p4
- double p5
- double p6
- double p7
- double p8
- double p9
- double p10
- double p11
- long p12
- long p13

4.4.1 Detailed Description

A structure passed to the integrators to hold the parameters fixed in the integration.

4.4.2 Field Documentation

4.4.2.1 p1 `double p1`

4.4.2.2 p10 `double p10`

4.4.2.3 p11 `double p11`

4.4.2.4 p12 `long p12`

4.4.2.5 p13 `long p13`

4.4.2.6 p2 `double p2`

4.4.2.7 p3 `double p3`

4.4.2.8 p4 `double p4`

4.4.2.9 p5 `double p5`

4.4.2.10 p6 `double p6`

4.4.2.11 p7 `double p7`

4.4.2.12 p8 `double p8`

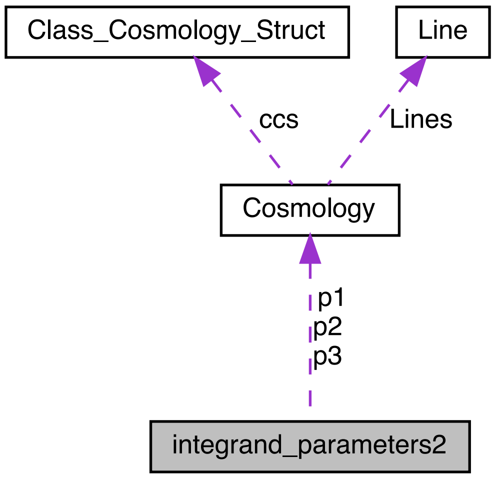
4.4.2.13 p9 `double p9`

4.5 integrand_parameters2 Struct Reference

Another structure passed to the integrators to hold the parameters fixed in the integration.

`#include <header.h>`

Collaboration diagram for integrand_parameters2:



Data Fields

- struct Cosmology * p1
- struct Cosmology * p2
- struct Cosmology * p3
- double p4
- double p5
- double p6
- double p7
- double p8
- double p9

- double p10
- double p11
- double p12
- long p13
- long p14
- long p15
- long p16
- long p17
- long p18
- int p19
- double * p20
- size_t p22

4.5.1 Detailed Description

Another structure passed to the integrators to hold the parameters fixed in the integration.

4.5.2 Field Documentation

4.5.2.1 p1 `struct Cosmology* p1`

4.5.2.2 p10 `double p10`

4.5.2.3 p11 `double p11`

4.5.2.4 p12 `double p12`

4.5.2.5 p13 `long p13`

4.5.2.6 p14 `long p14`

4.5.2.7 p15 `long p15`

4.5.2.8 p16 `long p16`

4.5.2.9 p17 `long p17`

4.5.2.10 p18 `long p18`

4.5.2.11 p19 `int p19`

4.5.2.12 p2 `struct Cosmology* p2`

4.5.2.13 p20 `double* p20`

4.5.2.14 p22 `size_t p22`

4.5.2.15 p3 `struct Cosmology* p3`

4.5.2.16 p4 `double p4`

4.5.2.17 p5 `double p5`

4.5.2.18 p6 `double p6`

4.5.2.19 p7 `double p7`

4.5.2.20 p8 `double p8`

4.5.2.21 p9 `double p9`

4.6 Line Struct Reference

Structure that holds the Line-related quantities, including the interpolators for first and second moments of the line luminosity and the linear and quadratic luminosity-weighted line biases.

```
#include <Global_Structs.h>
```

Data Fields

- long LineType
- int initialized
- size_t npointsInterp
- double line_freq
- gsl_interp_accel ∗ mom1_accel_ptr
- gsl_spline ∗ mom1_spline_ptr
- gsl_interp_accel ∗ mom2_accel_ptr
- gsl_spline ∗ mom2_spline_ptr
- gsl_interp_accel ∗ b1_LW_accel_ptr
- gsl_spline ∗ b1_LW_spline_ptr
- gsl_interp_accel ∗ b2_LW_accel_ptr
- gsl_spline ∗ b2_LW_spline_ptr

4.6.1 Detailed Description

Structure that holds the Line-related quantities, including the interpolators for first and second moments of the line luminosity and the linear and quadratic luminosity-weighted line biases.

4.6.2 Field Documentation

4.6.2.1 b1_LW_accel_ptr `gsl_interp_accel* b1_LW_accel_ptr`

4.6.2.2 b1_LW_spline_ptr `gsl_spline* b1_LW_spline_ptr`

4.6.2.3 b2_LW_accel_ptr `gsl_interp_accel* b2_LW_accel_ptr`

4.6.2.4 b2_LW_spline_ptr `gsl_spline* b2_LW_spline_ptr`

4.6.2.5 initialized `int initialized`

4.6.2.6 line_freq `double line_freq`

4.6.2.7 LineType `long LineType`

4.6.2.8 mom1_accel_ptr `gsl_interp_accel* mom1_accel_ptr`

4.6.2.9 mom1_spline_ptr `gsl_spline* mom1_spline_ptr`

4.6.2.10 mom2_accel_ptr `gsl_interp_accel* mom2_accel_ptr`

4.6.2.11 mom2_spline_ptr `gsl_spline* mom2_spline_ptr`

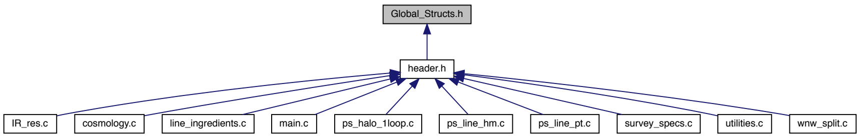
4.6.2.12 npointsInterp `size_t npointsInterp`

5 File Documentation

5.1 README.md File Reference

5.2 Global_Structs.h File Reference

This graph shows which files directly or indirectly include this file:



Data Structures

- struct Class_Cosmology_Struct

  Structure to store cosmology structure from CLASS code.
- struct Cosmology

  Structure that holds varioud quantities that need to be evaluated for a given choice of cosmological paramteres.
- struct Line

  Structure that holds the Line-related quantities, including the interpolators for first and second moments of the line luminosity and the linear and quadratic luminosity-weighted line biases.
- struct globals

  A global structure including the values of cosmological parmaeters, 2d interpolator of SFR, and names of various files.

5.3 Global_Structs.h

Go to the documentation of this file.

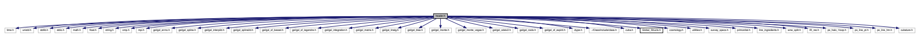
```
#ifndef GLOBALSTRUCTS_H_
#define GLOBALSTRUCTS_H_


struct Class_Cosmology_Struct{

    struct precision                    pr;              /* for precision parameters */
    struct background                   ba;              /* for cosmological background */
    struct thermo                       th;              /* for thermodynamics */
    struct perturbs                     pt;              /* for source functions */
    struct transfers                    tr;              /* for transfer functions */
    struct primordial                   pm;              /* for primordial spectra */
    struct spectra                      sp;              /* for output spectra */
    struct nonlinear                    nl;              /* for non-linear spectra */
    struct lensing                      le;              /* for lensed spectra */
    struct output                       op;              /* for output files */
    ErrorMsg errmsg;                    /* for error messages */
};


struct Cosmology
{

     struct Class_Cosmology_Struct    ccs;
     struct Line                      **Lines;

     int                              NLines;
     long                             mode_nu;
```

```

    double cosmo_pars[6];
};



struct Line
{
      long                    LineType;
      int                     initialized;
      size_t                  npointsInterp;

      double                  line_freq;

      gsl_interp_accel        *mom1_accel_ptr;
      gsl_spline              *mom1_spline_ptr;
      gsl_interp_accel        *mom2_accel_ptr;
      gsl_spline              *mom2_spline_ptr;

      gsl_interp_accel        *b1_LW_accel_ptr;
      gsl_spline              *b1_LW_spline_ptr;
      gsl_interp_accel        *b2_LW_accel_ptr;
      gsl_spline              *b2_LW_spline_ptr;

};


struct globals
{
    double H0;
    double c;

    double As;
    double logAs;
    double ns;
    double h;
    double Omega_cdm;
    double Omega_b;
    double Omega_r;
    double Omega_lambda;
    double Omega_g;
    double Omega_nu;

    double b1;
    double sigFOG0;

    long Npars;
    double z_i;
    double rho;
    double mass;
    double kp;
    double ng;
    double volume;

    double kf;
    double h_m;

    double M_min;
    double M_max;
    double z_max;

    char project_home[FILENAME_MAX];
    char output_dir[FILENAME_MAX];
    char data_dir[FILENAME_MAX];
    char data_priors[FILENAME_MAX];


    // Min and max values
    double              PS_kmin;
    double              PS_kmax;

    // File names
    char            SFR_filename[FILENAME_MAX];
    char            Planck_Fisher_filename[FILENAME_MAX];

    gsl_interp_accel    *logM_accel_ptr;
    gsl_interp_accel    *z_accel_ptr;
    gsl_spline2d        *logSFR_spline2d_ptr;
};

#endif
```

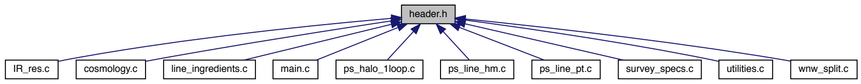
5.4 header.h File Reference

```
#include <time.h>
#include <unistd.h>
#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <float.h>
#include <string.h>
#include <omp.h>
#include <mpi.h>
#include <gsl/gsl_errno.h>
#include <gsl/gsl_spline.h>
#include <gsl/gsl_interp2d.h>
#include <gsl/gsl_spline2d.h>
#include <gsl/gsl_sf_bessel.h>
#include <gsl/gsl_sf_legendre.h>
#include <gsl/gsl_integration.h>
#include <gsl/gsl_matrix.h>
#include <gsl/gsl_linalg.h>
#include <gsl/gsl_blas.h>
#include <gsl/gsl_monte.h>
#include <gsl/gsl_monte_vegas.h>
#include <gsl/gsl_odeiv2.h>
#include <gsl/gsl_roots.h>
#include <gsl/gsl_sf_expint.h>
#include <ctype.h>
#include "../Class/include/class.h"
#include "cuba.h"
#include "Global_Structs.h"
#include "cosmology.h"
#include "utilities.h"
#include "survey_specs.h"
#include "primordial.h"
#include "line_ingredients.h"
#include "wnw_split.h"
#include "IR_res.h"
#include "ps_halo_1loop.h"
#include "ps_line_pt.h"
#include "ps_line_hm.h"
#include "cubature.h"
```

Include dependency graph for header.h:



This graph shows which files directly or indirectly include this file:



Data Structures

- struct integrand_parameters

    A structure passed to the integrators to hold the parameters fixed in the integration.
- struct integrand_parameters2

    Another structure passed to the integrators to hold the parameters fixed in the integration.

Macros

- #define _GNU_SOURCE
- #define PSC 101L

    For solving ODER.
- #define ST 102L
- #define TR 103L
- #define GROWTH 104L
- #define DERGROWTH 105L
- #define NONLINEAR 106L
- #define LINEAR 107L
- #define GAUSSIAN 114L
- #define NONGAUSSIAN 115L
- #define INIT 116L
- #define LOCAL 117L
- #define EQUILATERAL 118L
- #define ORTHOGONAL 119L
- #define QSF 120L
- #define HS 121L
- #define NGLOOP 122L
- #define derNGLOOP 123L
- #define QUADRATIC 124L
- #define TIDE 125L
- #define GAMMA 126L
- #define LPOWER 127L
- #define NLPOWER 128L
- #define TRANS 129L
- #define DER 130L
- #define CO10 131L
- #define CO21 132L
- #define CO32 133L
- #define CO43 134L
- #define CO54 135L
- #define CO65 136L
- #define CII 137L
- #define MATTER 138L
- #define LINEMATTER 139L

- #define LINE 140L
- #define DST 141L
- #define GFILTER 142L
- #define BSPLINE 143L
- #define TREE 144L
- #define LOOP 145L
- #define WIR 146L
- #define NOIR 147L
- #define HALO 148L
- #define PS_KMIN 1.0e-7
- #define PS_KMAX 1.0e4
- #define CLEANUP 1
- #define DO_NOT_EVALUATE -1.0
- #define MAXL 2000

Functions

- void initialize ()

  List of limHaloPT header files.
- void cleanup ()

5.4.1 Macro Definition Documentation

5.4.1.1 _GNU_SOURCE `#define _GNU_SOURCE`

5.4.1.2 BSPLINE `#define BSPLINE 143L`

5.4.1.3 CII `#define CII 137L`

5.4.1.4 CLEANUP `#define CLEANUP 1`

5.4.1.5 CO10 `#define CO10 131L`

5.4.1.6 CO21 `#define CO21 132L`

5.4.1.7 CO32 `#define CO32 133L`

5.4.1.8 CO43 `#define CO43 134L`

5.4.1.9 CO54 `#define CO54 135L`

5.4.1.10 CO65 `#define CO65 136L`

5.4.1.11 DER `#define DER 130L`

5.4.1.12 DERGROWTH `#define DERGROWTH 105L`

5.4.1.13 derNGLOOP `#define derNGLOOP 123L`

5.4.1.14 DO_NOT_EVALUATE `#define DO_NOT_EVALUATE -1.0`

5.4.1.15 DST `#define DST 141L`

5.4.1.16 EQUILATERAL `#define EQUILATERAL 118L`

5.4.1.17 GAMMA `#define GAMMA 126L`

5.4.1.18 GAUSSIAN `#define GAUSSIAN 114L`

5.4.1.19 GFILTER `#define GFILTER 142L`

5.4.1.20 GROWTH `#define GROWTH 104L`

5.4.1.21 HALO `#define HALO 148L`

5.4.1.22 HS `#define HS 121L`

5.4.1.23 INIT `#define INIT 116L`

5.4.1.24 LINE `#define LINE 140L`

5.4.1.25 LINEAR `#define LINEAR 107L`

5.4.1.26 LINEMATTER `#define LINEMATTER 139L`

5.4.1.27 LOCAL `#define LOCAL 117L`

5.4.1.28 LOOP `#define LOOP 145L`

5.4.1.29 LPOWER `#define LPOWER 127L`

5.4.1.30 MATTER `#define MATTER 138L`

5.4.1.31 MAXL `#define MAXL 2000`

5.4.1.32 NGLOOP `#define NGLOOP 122L`

5.4.1.33 NLPOWER `#define NLPOWER 128L`

5.4.1.34 NOIR `#define NOIR 147L`

5.4.1.35 NONGAUSSIAN `#define NONGAUSSIAN 115L`

5.4.1.36 NONLINEAR `#define NONLINEAR 106L`

5.4.1.37 ORTHOGONAL `#define ORTHOGONAL 119L`

5.4.1.38 PS_KMAX `#define PS_KMAX 1.0e4`

5.4.1.39 PS_KMIN `#define PS_KMIN 1.0e-7`

5.4.1.40 PSC `#define PSC 101L`

For solving ODER.

5.4.1.41 QSF `#define QSF 120L`

5.4.1.42 QUADRATIC `#define QUADRATIC 124L`

5.4.1.43 ST `#define ST 102L`

5.4.1.44 TIDE `#define TIDE 125L`

5.4.1.45 TR `#define TR 103L`

5.4.1.46 TRANS `#define TRANS 129L`

5.4.1.47 TREE `#define TREE 144L`

5.4.1.48 WIR `#define WIR 146L`

5.4.2 Function Documentation

5.4.2.1 cleanup() `void cleanup ( )`

5.4.2.2 initialize() `void initialize ( )`

List of limHaloPT header files.

Function declarations of main.c module

List of limHaloPT header files.

The global structure "gb" have several elements to hold the paths to project source directory, input, and output folders, and values of cosmological parmaeters.

Returns

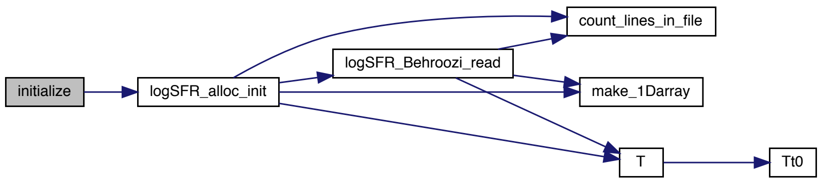
void

Change the path to the parent directory

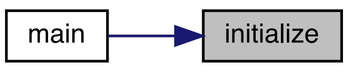
In units of km/s

omega_b = Omega_b h^2;

3.0665Here is the call graph for this function:



Here is the caller graph for this function:



5.5 header.h

Go to the documentation of this file.

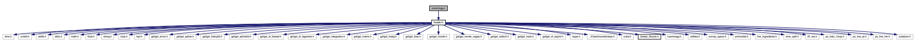
```
#ifndef HEADER_H_
#define HEADER_H_

#define _GNU_SOURCE

#include <time.h>
#include <unistd.h>
#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <float.h>
#include <string.h>
#include <omp.h>
#include <mpi.h>
#include <gsl/gsl_errno.h>
#include <gsl/gsl_spline.h>
#include <gsl/gsl_interp2d.h>
#include <gsl/gsl_spline2d.h>
#include <gsl/gsl_sf_bessel.h>
#include <gsl/gsl_sf_legendre.h>
#include <gsl/gsl_integration.h>
#include <gsl/gsl_matrix.h>
#include <gsl/gsl_linalg.h>
#include <gsl/gsl_blas.h>
#include <gsl/gsl_monte.h>
#include <gsl/gsl_monte_vegas.h>
#include <gsl/gsl_odeiv2.h>
#include <gsl/gsl_roots.h>   // For finding the root of algebraic equation
#include <gsl/gsl_sf_expint.h>
#include <ctype.h>
#include "../Class/include/class.h"
#include "cuba.h"


#define PSC         101L
#define ST              102L
#define TR              103L

#define GROWTH      104L
#define DERGROWTH       105L

#define NONLINEAR       106L
#define LINEAR      107L

#define GAUSSIAN        114L
#define NONGAUSSIAN 115L

#define INIT        116L
#define LOCAL       117L
#define EQUILATERAL 118L
#define ORTHOGONAL  119L
#define QSF         120L
#define HS          121L
#define NGLOOP      122L
#define derNGLOOP       123L

#define QUADRATIC       124L
#define TIDE        125L
#define GAMMA       126L

#define LPOWER      127L
#define NLPOWER     128L
#define TRANS       129L
#define DER         130L

#define CO10        131L
#define CO21        132L
#define CO32        133L
#define CO43        134L
#define CO54        135L
#define CO65        136L
#define CII         137L

#define MATTER      138L
#define LINEMATTER  139L
#define LINE        140L

#define DST         141L
#define GFILTER     142L
#define BSPLINE     143L

```

```
#define TREE        144L
#define LOOP        145L
#define WIR         146L
#define NOIR        147L

#define HALO        148L


#define PS_KMIN        1.0e-7
#define PS_KMAX        1.0e4

#define CLEANUP        1

#define DO_NOT_EVALUATE -1.0

#define MAXL 2000

#include "Global_Structs.h"
#include "cosmology.h"
#include "utilities.h"
#include "survey_specs.h"
#include "primordial.h"
#include "line_ingredients.h"
#include "wnw_split.h"
#include "IR_res.h"
#include "ps_halo_1loop.h"
#include "ps_line_pt.h"
#include "ps_line_hm.h"
#include "cubature.h"


void  initialize();
void    cleanup();


struct integrand_parameters
{
    double p1;
    double p2;
    double p3;
    double p4;
    double p5;
    double p6;
    double p7;
    double p8;
    double p9;
    double p10;
    double p11;
    long    p12;
    long    p13;
};

struct integrand_parameters2
{

    struct Cosmology *p1;
    struct Cosmology *p2;
    struct Cosmology *p3;

    double p4;
    double p5;
    double p6;
    double p7;
    double p8;
    double p9;
    double p10;
    double p11;
    double p12;

    long p13;
    long p14;
    long p15;
    long p16;
    long p17;
    long p18;

    int p19;

    double *p20;
    size_t p22;
};


#endif


```

5.6 cosmology.c File Reference

Documented cosmology module.

`#include "header.h"`
Include dependency graph for cosmology.c:



Functions

- int Cosmology_init (struct Cosmology ∗Cx, double pk_kmax, double pk_zmax, int nlines, int ∗line_types, size_t npoints_interp, double M_min, long mode_mf)

    Allocate memory and initialize the cosmology structure, which includes the CLASS cosmology structure and line strucrure.
- int Cosmology_free (struct Cosmology ∗Cx)

    Free the memory allocated to cosmology structure.
- int CL_Cosmology_initilize (struct Cosmology ∗Cx, double pk_kmax, double pk_zmax)

    Allocate memory and initialize the CLASS cosmology structure.
- int CL_Cosmology_free (struct Cosmology ∗Cx)

    Free the memory allocated to CLASS cosmology structure.
- double Pk_dlnPk (struct Cosmology ∗Cx, double k, double z, int mode)

    Compute the matter power spectra (in unit of (Mpc)^3) as a function of k (in unit of 1/Mpc) and z, Setting the switch "mode", to LINEAR or NONLINEAR, we can compute the linear or nonlinear spectrum respectively.
- double Pk_dlnPk_HV (struct Cosmology ∗Cx, double k, double z, int mode)

    Read in the linear power spectrum, used to set the initial conditions of Hidden-Valley sims.
- double Mk_dlnMk (struct Cosmology ∗Cx, double k, double z, int mode)

    Compute the transfer function for different species depending on the switch "mode", which can be set to cdm, baryons or total matter transfer function.
- double sig_sq_integrand (double x, void ∗par)

    The integrand function passed to qags integrator to compute the variance of the matter density.
- double sig_sq (struct Cosmology ∗Cx, double z, double R)

    Compute variance of smoothed matter density fluctuations.
- double der_lnsig_sq (struct Cosmology ∗Cx, double z, double R)

    Compute the logarithmic derivative of the variance of smoothed matter density fluctuations w.r.t.
- double sigma0_sq_integrand (double x, void ∗par)

    The integrand function passed to qags integrator to compute the variance of the unsmoothed matter density.
- double sigma0_sq (struct Cosmology ∗Cx, double z, double kmax)

    Compute variance of unsmoothed matter density fluctuations.
- double growth_D (struct Cosmology ∗Cx, double z)

    Compute the growth factor D(k,z) which is scale-indep if mode_nu = NUM, and scale-dep if mode_nu = MASS The scale-dep growth is calculated by taking the ratio of the transfer function at redshift z and zero.
- double growth_f (struct Cosmology ∗Cx, double z)

    Compute the scale-dependant linear growth rate f(k,z) (i.e the velocity growth factor) by taking numerical derivative of the scale_dep_growth_D() function f(k,a) = d ln D(k,a)/d ln a.

- double Hubble (struct Cosmology ∗Cx, double z)

  Compute the the hubble rate (exactly the quantity defined by CLASS as index_bg_H in the background module).
- double angular_distance (struct Cosmology ∗Cx, double z)

  Compute the angular diameter distance (exactly the quantity defined by CLASS as ba.index_bg_ang_distance in the background module).
- double comoving_radial_distance (struct Cosmology ∗Cx, double z)

  Compute the comoving radial distance
- double rhoc (struct Cosmology ∗Cx, double z)

  Compute the critical density in unit of M_sun/Mpc^3.
- double R_scale (struct Cosmology ∗Cx, double M)

  Compute the Lagrangian radius of halos in unit of 1/Mpc^3 , fixing z=0.
- double R_vir (struct Cosmology ∗Cx, double M)

  Compute the comoving virial radius of halos in unit of 1/Mpc^3, which is defined as the radius at which the average density within this radius is Delta X rho_c.
- double concentration_cdm (double M, double z)

  Compute the cold dark matter concentration-mass relation.
- double nfw_profile (struct Cosmology ∗Cx, double k, double M, double z)

  Compute the NFW halo profile in Fourier space, given by Eq.
- double window_rth (double k, double R)

  Fourier transform of top-hat window in real space.
- double derR_window_rth (double k, double R)

  Derivative w.r.t.
- double window_kth (double k, double R)

  Top-hat window in Fourier space.
- double window_g (double k, double R)

  Gaussian window.
- double derR_logwindow_g (double k, double R)

  Derivative w.r.t smoothing scale of Gaussian window.

Variables

- struct globals gb

5.6.1 Detailed Description

Documented cosmology module.

Azadeh Moradinezhad Dizgah, November 4th 2021

The first routine of this module initalizes the Cosmology structure, which is the main building block of this entire code. This structure includes two sub-structures: the CLASS cosmology structure and line structure. Once the CLASS cosmology is initialized, various useful functions can be directly called from CLASS, example to compute matter power spectrum and transfer function, angular and comoving radii, growth factor and growth rate, variance of matter fluctuations and its derivative. Lastly, the module also includes various window functions and their derivatives.

In summary, the following functions can be called from other modules:

1. Cosmology_init() allocates memory to and initializes cosmology structure
2. Cosmology_free() frees the memory allocated to cosmology structure

3. CL_Cosmology_initilize() initializes the class cosmology structure
4. CL_Cosmology_free() frees the class cosmology structure
5. PS() computes matter power spectrum calling class function
6. Transfer() computes matter transfer function calling class function
7. growth_D() computes the scale-dep growth factor
8. growth_f() computes the scale-dep growth rate dlnD(k,a)/dlna
9. scale_indep_growth_D() computes the scale-indep growth factor using directly CLASS functions
10. scale_indep_growth_f() computes the scale-indep growth rate dlnD(k,a)/dlna using directly CLASS functions
11. Hubble() computes hubbble parameter using directly CLASS functions
12. angular_distance() computes angular diamtere distance using directly CLASS functions
13. comoving_radial_distance() computes radial distance using directly CLASS functions
14. sig_sq() computes variance of smoothed matter fluctuations
15. der_sig_sq() computes derivative of the variance of smoothed matter fluctuations w.r.t. smoothing scale
16. sigma0_sq() computes variance of unsmoothed matter fluctuations
17. rhoc() computes the critical density of the universe
18. R_scale() computes the size of a spherical halo corresponding to a given mass at z=0
19. R_scale_wrong() computes the size of a spherical halo corresponding to a given mass at a given redshift
20. window_rth() computes top-hat filter in real space
21. window_g() computes Gaussian window
22. window_kth() computes top-hat filter in Fourier space
23. derR_window_rth() computes derivative of top-hat filter in real space w.r.t. smoothing scale
24. derR_logwindow_g() computes derivative of top-hat filter in Fourier space w.r.t. smoothing scale

5.6.2 Function Documentation

5.6.2.1 angular_distance()

```
double angular_distance (
        struct Cosmology * Cx,
        double z )
```

Compute the angular diameter distance (exactly the quantity defined by CLASS as ba.index_bg_ang_distance in the background module).

luminosity distance d_L = (1+z) d_M angular diameter distance d_A = d_M/(1+z) where d_M is the transverse comoving distance, which is equal to comoving distance for flat cosmology and has a dependance on curvature for non-flat cosmologies, as described in lines 849 - 851

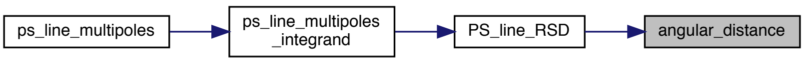
Parameters

Cx	Input↩ : pointer to Cosmology structure
z	Input↩ : redshift to compute the spectrum

Returns

D_A

junkHere is the caller graph for this function:



5.6.2.2 CL_Cosmology_free()

```
int CL_Cosmology_free (
    struct Cosmology * Cx )
```

Free the memory allocated to CLASS cosmology structure.

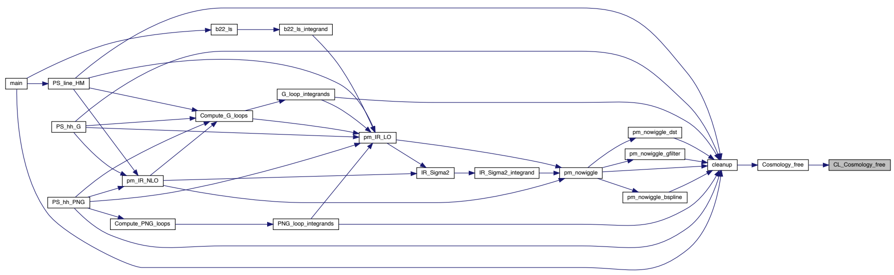
Parameters

Cx	Input↩ : pointer to Cosmology structure

Returns

the error status

Here is the caller graph for this function:



5.6.2.3 CL_Cosmology_initilize()

```
int CL_Cosmology_initilize (
        struct Cosmology * Cx,
        double pk_kmax,
        double pk_zmax )
```

Allocate memory and initialize the CLASS cosmology structure.

Parameters

Cx	Input↩ : pointer to Cosmology structure
pk_kmax	Input↩ : kmax for computation of matter power spectrum by CLASS
pk_zmax	Input↩ : zmax for computation of matter power spectrum by CLASS

Returns

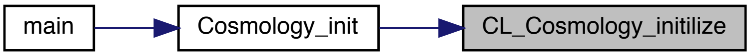
the error status

h

Omega_b

Omega_b

pivot scale in unit of 1/MpcHere is the caller graph for this function:



5.6.2.4 comoving_radial_distance()

```
double comoving_radial_distance (
    struct Cosmology * Cx,
    double z )
```

Compute the comoving radial distance

Parameters

Cx	Input←: pointer to Cosmology structure
z	Input←: redshift to compute the spectrum

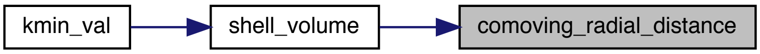
Returns

the double value D_c

junk

For a flat cosmology, comoving distance is equal to conformal distance. This pieace of code is how the comving distance for flat and nonflat cases are computed. Chnage the expression of D_A below According to this if considering non-flat cosmology.

Here is the caller graph for this function:



5.6.2.5 concentration_cdm()

```
double concentration_cdm (
    double M,
    double z )
```

Compute the cold dark matter concentration-mass relation.

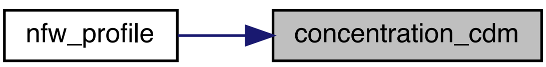
Parameters

M	Input↩ : halo mass in unit of solar mass
z	Input↩ : redshift of interest

Returns

the cdm concentration

Here is the caller graph for this function:



5.6.2.6 Cosmology_free()

```
int Cosmology_free (
    struct Cosmology * Cx )
```

Free the memory allocated to cosmology structure.

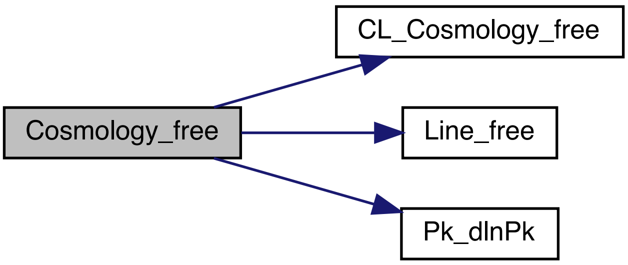
Parameters

Cx	Input: pointer to Cosmology structure

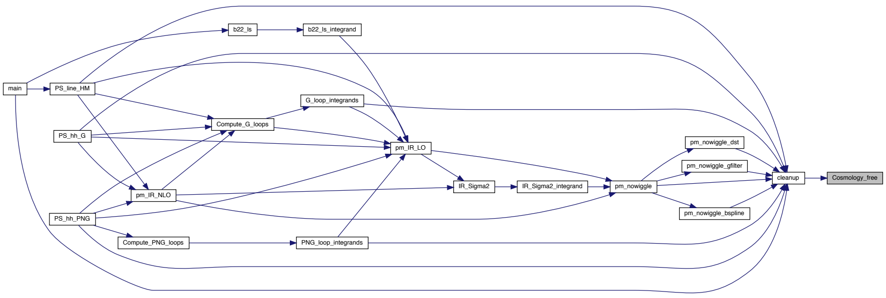
Returns

the error status

Here is the call graph for this function:



Here is the caller graph for this function:



5.6.2.7 Cosmology_init()

```
int Cosmology_init (
    struct Cosmology * Cx,
    double pk_kmax,
    double pk_zmax,
    int nlines,
    int * line_types,
    size_t npoints_interp,
    double M_min,
    long mode_mf )
```

Allocate memory and initialize the cosmology structure, which includes the CLASS cosmology structure and line strucrure.

Parameters

Cx	Input↩ : pointer to Cosmology structure
pk_kmax	Input↩ : kmax for computation of matter power spectrum by CLASS
pk_zmax	Input↩ : zmax for computation of matter power spectrum by CLASS
nlines	Input↩ : number of lines whose properties we want to compute

Parameters

line_type	Input← : name of the line to compute. It can be set to CII, CO10, CO21, CO32, CO43, CO54, CO65
npoints_interp	Input← : number of points in redshift for interpolation of line properties
M_min	Input← : minimum halo mass for mass integrals

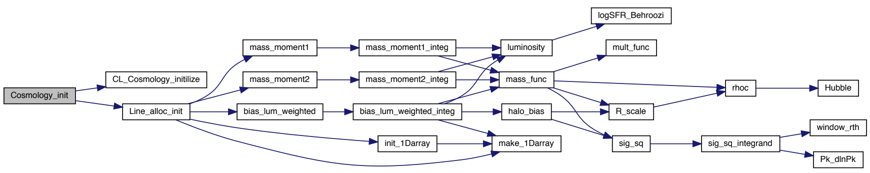
Parameters

mode_mf	Inpute : theoretical model of halo mass function to use. It can be set to sheth-Tormen (ST), Tinker (TR) or Press-Schecter (PSC)

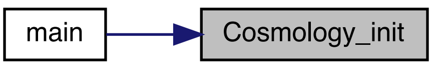
Returns

an integer if succeeded

Here is the call graph for this function:



Here is the caller graph for this function:



5.6.2.8 der_lnsig_sq()

```
double der_lnsig_sq (
        struct Cosmology * Cx,
        double z,
        double R )
```

Compute the logarithmic derivative of the variance of smoothed matter density fluctuations w.r.t.

smoothing scale

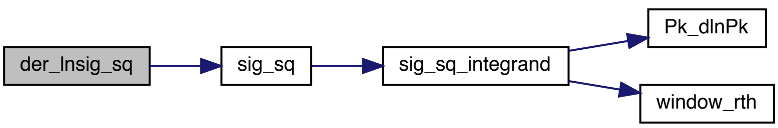
Parameters

Cx	Input: pointer to Cosmology structure
z	Input: redshift to compute the spectrum
R	Input: smoothing scale in unit of Mpc

Returns

the log-derivative of variance

Here is the call graph for this function:



5.6.2.9 derR_logwindow_g()

```
double derR_logwindow_g (
        double k,
        double R )
```

Derivative w.r.t smoothing scale of Gaussian window.

Parameters

k	Input← : wavenumber in unit of 1/Mpc
R	Input← : smoothing scale in unit of Mpc

Returns

the derivative of the window function

5.6.2.10 derR_window_rth()

```
double derR_window_rth (
        double k,
        double R )
```

Derivative w.r.t.

smoothing scale of the Fourier transform of top-hat window in real space

Parameters

k	Input← : wavenumber in unit of 1/Mpc
R	Input← : smoothing scale in unit of Mpc

Returns

the derivative of the window function

5.6.2.11 growth_D()

```
double growth_D (
    struct Cosmology * Cx,
    double z )
```

Compute the growth factor D(k,z) which is scale-indep if mode_nu = NUM, and scale-dep if mode_nu = MASS The scale-dep growth is calculated by taking the ratio of the transfer function at redshift z and zero.

The scale-indep growth is computed by CLASS directly The switch "mode" can be set to CDM, BA, TOT to return the growth factor of cdm, baryon and total matter.

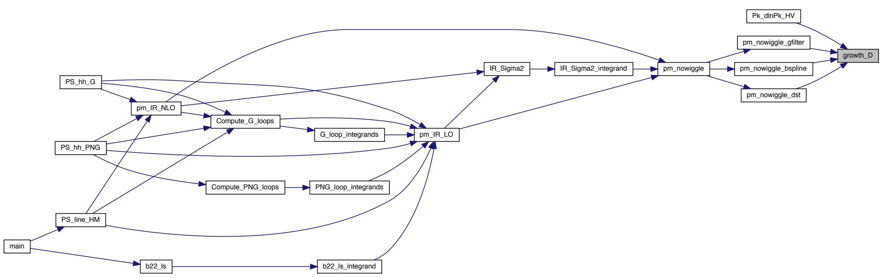
Parameters

Cx	Input↩ : pointer to Cosmology structure
k	Input↩ : wavenumber in unit of 1/Mpc
z	Input↩ : redshift to compute the spectrum

Returns

the growth factor, can be k-dep (ex. with nonzero neutrino mass)

junkHere is the caller graph for this function:



5.6.2.12 growth_f() `double growth_f ( struct Cosmology * Cx, double z )`

Compute the scale-dependant linear growth rate f(k,z) (i.e the velocity growth factor) by taking numerical derivative of the scale_dep_growth_D() function f(k,a) = d ln D(k,a)/d ln a.

The switch "mode" can be set to CDM, BA, TOT to return the growth factor of the corresponding matter component.

This is a useful function when constraining physics that induces scale-dependant growth such as massive neutrinos.

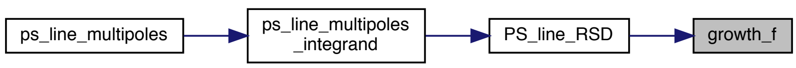
Parameters

Cx	Input : pointer to Cosmology structure
k	Input : wavenumber in unit of 1/Mpc
z	Input : redshift to compute the spectrum

Returns

the growth rate, can be k-dep (ex. with nonzero neutrino mass)

junkHere is the caller graph for this function:



5.6.2.13 Hubble() `double Hubble ( struct Cosmology * Cx, double z )`

Compute the the hubble rate (exactly the quantity defined by CLASS as index_bg_H in the background module).

This function is to a good approximation equal to Hubble(a,Cx) = gb.h*sqrt(Eofa(a,Cx))

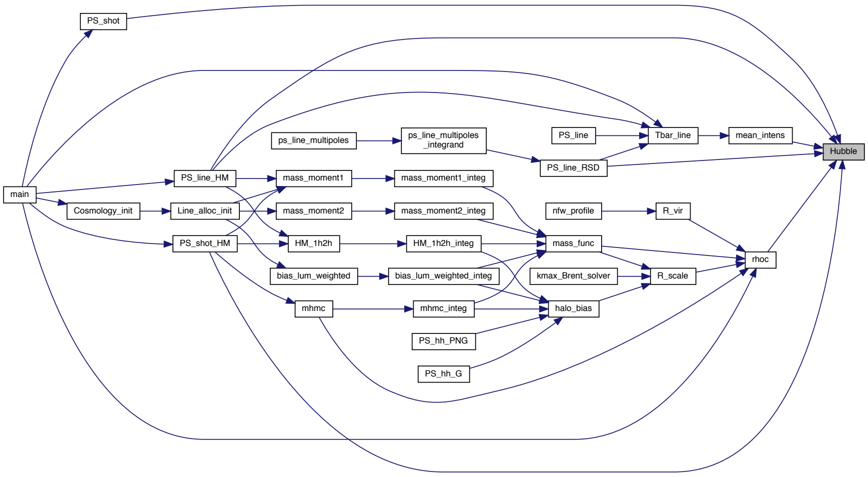
Parameters

Cx	Input : pointer to Cosmology structure
z	Input : redshift to compute the spectrum

Returns

the hubble parameter

junkHere is the caller graph for this function:



5.6.2.14 Mk_dlnMk()

```
double Mk_dlnMk (
    struct Cosmology * Cx,
    double k,
    double z,
    int mode )
```

Compute the transfer function for different species depending on the switch "mode", which can be set to cdm, baryons or total matter transfer function.

CLASS function spectra_tk_at_k_and_z() routine evaluates the matter transfer functions at a given value of k and z by interpolating in a table of all $T_i(k, z)$'s computed at this z by spectra_tk_at_z() (when kmin $<=$ k $<=$ kmax). Returns an error when k<kmin or k $>$ kmax.

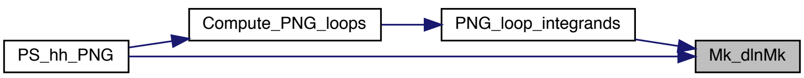
Parameters

Cx	Input : pointer to Cosmology structure
k	Input : wavenumber in unit of 1/Mpc
z	Input : redshift to compute the spectrum
mode	Input : switch to decide for which species we want to get the transfer function

Returns

the transfer function

Here is the caller graph for this function:



5.6.2.15 nfw_profile()

```
double nfw_profile (
    struct Cosmology * Cx,
    double k,
    double M,
    double z )
```

Compute the NFW halo profile in Fourier space, given by Eq.

3.7 of 2004.09515 The profile is normalized to unity at k->0, (see fig 3 of 1003.4740)

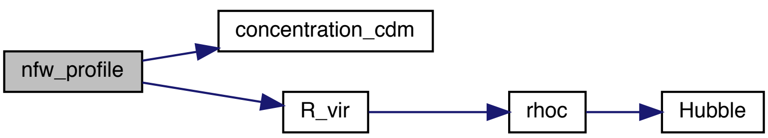
Parameters

Cx	Input: pointer to Cosmology structure
k	Input: wavenumber in unit of 1/Mpc
M	Input: halo mass in unit of solar mass
z	Input: redshift of interest

Returns

the nfw profile

rho_s is computed by enforcing int dr r^2 u(r) = 1Here is the call graph for this function:



5.6.2.16 Pk_dlnPk()

```
double Pk_dlnPk (
    struct Cosmology * Cx,
    double k,
    double z,
    int mode )
```

Compute the matter power spectra (in unit of (Mpc)^3) as a function of k (in unit of 1/Mpc) and z, Setting the switch "mode", to LINEAR or NONLINEAR, we can compute the linear or nonlinear spectrum respectively.

The CLASS spectra_pk_at_k_and_z() and spectra_pk_nl_at_k_and_z, evaluate the matter power spectrum at a given value of k and z by interpolating in a table of all P(k)'s computed at this z by spectra_pk_at_z() (when kmin <= k <= kmax), or eventually by using directly the primordial spectrum (when 0 <= k < kmin): the latter case is an approximation, valid when kmin << comoving Hubble scale today. Returns zero when k=0. Returns an error when k<0 or k > kmax.

Parameters

Cx	Input : pointer to Cosmology structure
k	Input : wavenumber in unit of 1/Mpc
z	Input : redshift to compute the spectrum

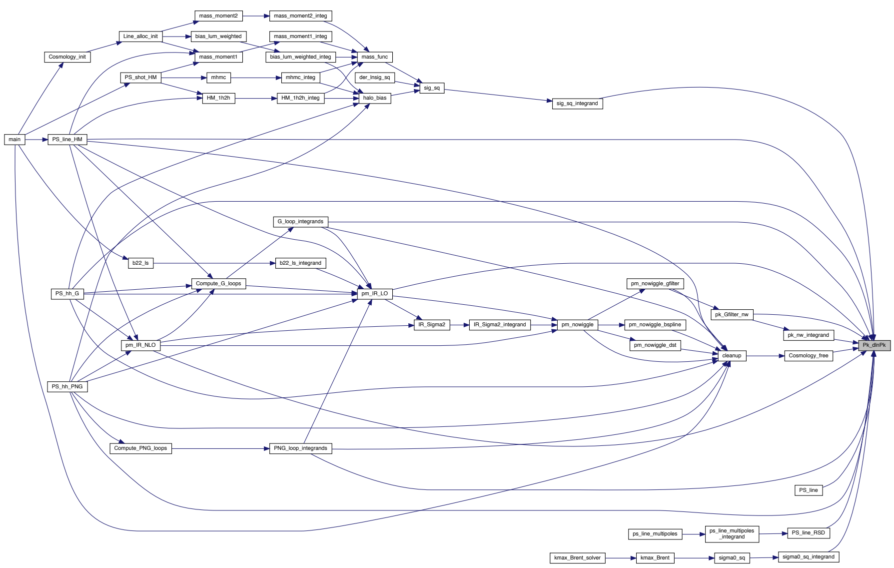
Parameters

modes	Input: switch to decide whether to compute linear or non-linear spectrum It can be set to sheth-Tormen (ST), Tinker (TR) or Press-Schecter (PSC)

Returns

the double value of matter power spectrum

Here is the caller graph for this function:



5.6.2.17 Pk_dlnPk_HV()

```
double Pk_dlnPk_HV (
    struct Cosmology * Cx,
    double k,
    double z,
    int mode )
```

Read in the linear power spectrum, used to set the initial conditions of Hidden-Valley sims.

Input k is in unit of 1/Mpc. First convert it to h/Mpc, and also convert the final matter power spectrum in unit of (Mpc/h)^3

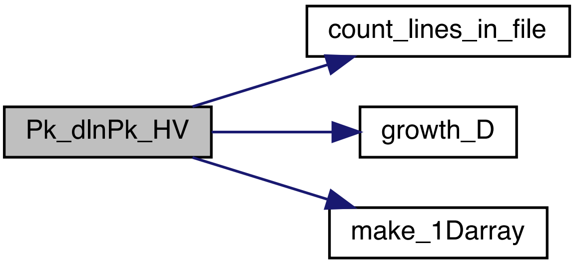
Parameters

Cx	Input: pointer to Cosmology structure
k	Input: wavenumber in unit of 1/Mpc
z	Input: redshift to compute the spectrum
mode	Input: switch to decide whether to evaluate the interpolator of the power spectrum or free the interpolator

Returns

the HV linear matter power spectrum

Here is the call graph for this function:



5.6.2.18 R_scale()

```
double R_scale (
        struct Cosmology * Cx,
        double M )
```

Compute the Lagrangian radius of halos in unit of 1/Mpc^3 , fixing z=0.

Parameters

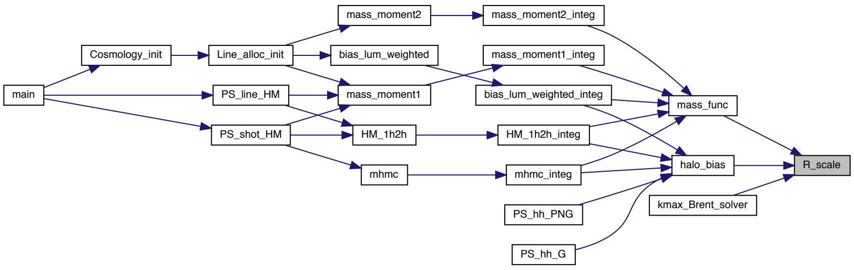
Cx	Input: pointer to Cosmology structure
h_mass	Input: halo mass in unit of solar mass

Returns

R_s

Here is the call graph for this function:

Here is the caller graph for this function:



5.6.2.19 R_vir()

```
double R_vir (
    struct Cosmology * Cx,
    double M )
```

Compute the comoving virial radius of halos in unit of 1/Mpc^3, which is defined as the radius at which the average density within this radius is Delta X rho_c.

Parameters

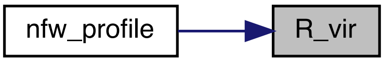
Cx	Input : pointer to Cosmology structure
M	Input : halo mass in unit of solar mass

Returns

R_vir

Here is the call graph for this function:

Here is the caller graph for this function:



5.6.2.20 rhoc()

```
double rhoc (
    struct Cosmology * Cx,
    double z )
```

Compute the critical density in unit of M_sun/Mpc^3.

Parameters

Cx	Input : pointer to Cosmology structure
z	Input : redshift to compute the spectrum

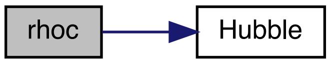
Returns

the double value of rho_c

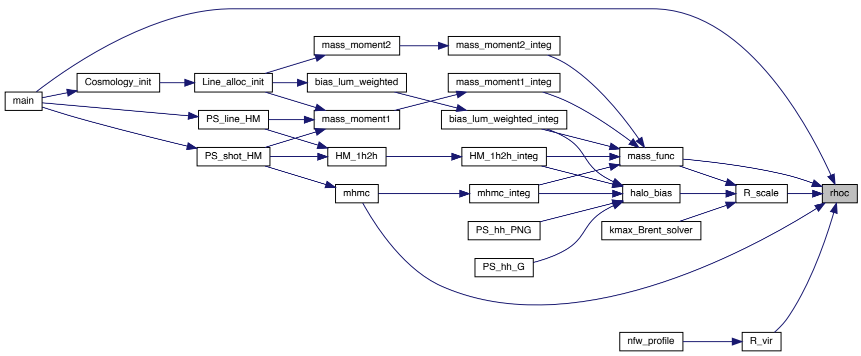
E (a) = H(a)^2/H0^2

G is in unit of m^3 kg^-1 s^-2, conversion factor from m to Mpc

To convert to solar massHere is the call graph for this function:



Here is the caller graph for this function:



5.6.2.21 sig_sq()

```
double sig_sq (
        struct Cosmology * Cx,
        double z,
        double R )
```

Compute variance of smoothed matter density fluctuations.

The function sig_sq_integrand() defines the integrand and sig_sq() computes the k-integral

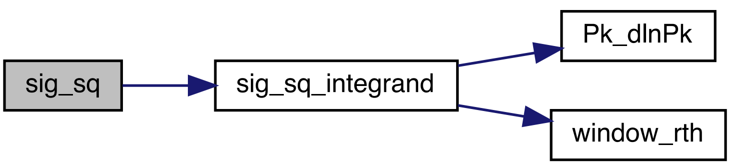
Parameters

Cx	Input : pointer to Cosmology structure
z	Input : redshift to compute the spectrum
R	Input : smoothing scale in unit of Mpc

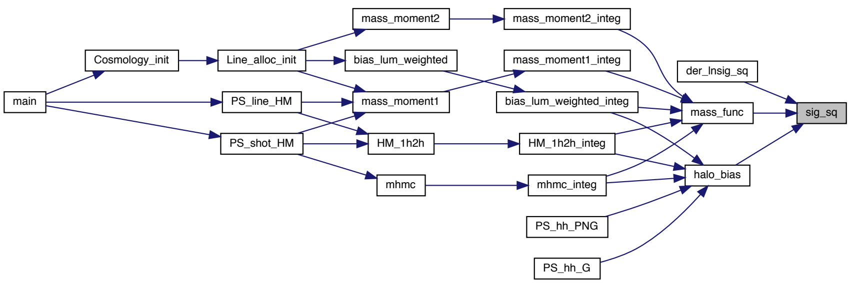
Returns

the variance

Here is the call graph for this function:



Here is the caller graph for this function:



5.6.2.22 sig_sq_integrand() `double sig_sq_integrand ( double x, void * par )`

The integrand function passed to qags integrator to compute the variance of the matter density.

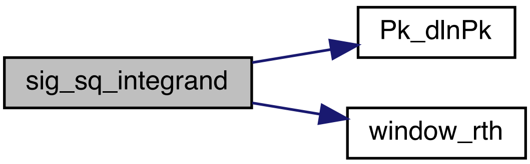
Parameters

x	Input: integration variable
par	Input: integration parmaeters

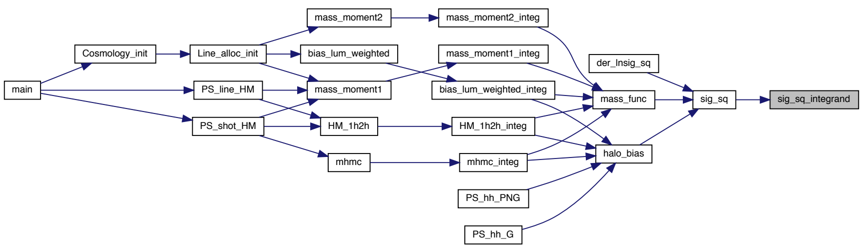
Returns

value of the integrand

Here is the call graph for this function:



Here is the caller graph for this function:



5.6.2.23 sigma0_sq()

```
double sigma0_sq (
    struct Cosmology * Cx,
    double z,
    double kmax )
```

Compute variance of unsmoothed matter density fluctuations.

The function sigma0_integrand() defines the integrand and sigma0_sq() computes the k-integral

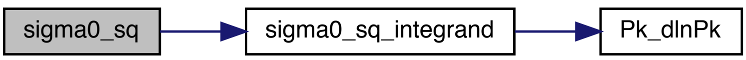
Parameters

Cx	Input↩ : pointer to Cosmology structure
z	Input↩ : redshift to compute the spectrum

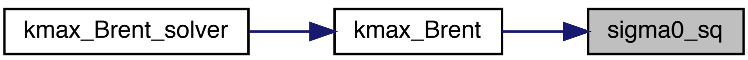
Returns

the unsmoothed variance kmax is in unit of 1/Mpc

Here is the call graph for this function:



Here is the caller graph for this function:



5.6.2.24 sigma0_sq_integrand()

```
double sigma0_sq_integrand (
    double x,
    void * par )
```

The integrand function passed to qags integrator to compute the variance of the unsmoothed matter density.

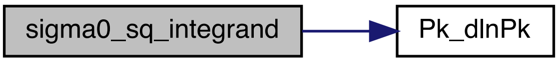
Parameters

x	Input↩ : integration variable
par	Input↩ : integration parmaeters

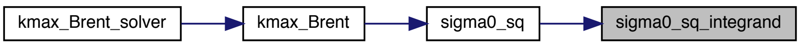
Returns

value of the integrand

Here is the call graph for this function:



Here is the caller graph for this function:



5.6.2.25 window_g()

```
double window_g (
    double k,
    double R )
```

Gaussian window.

Parameters

k	Input←↩ : wavenumber in unit of 1/Mpc
R	Input←↩ : smoothing scale in unit of Mpc

Returns

the window function

5.6.2.26 window_kth()

```
double window_kth (
        double k,
        double R )
```

Top-hat window in Fourier space.

Parameters

k	Input←↩ : wavenumber in unit of 1/Mpc
R	Input←↩ : smoothing scale in unit of Mpc

Returns

the window function

5.6.2.27 window_rth()

```
double window_rth (
        double k,
        double R )
```

Fourier transform of top-hat window in real space.

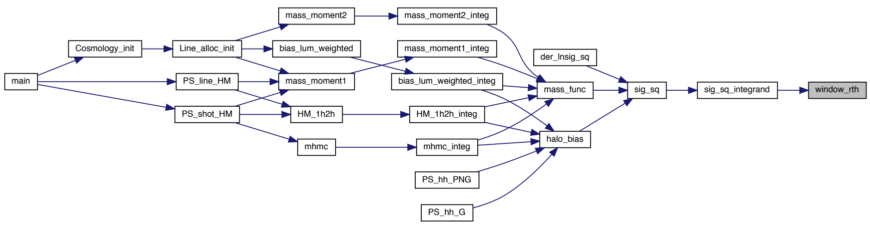
Parameters

k	Input : wavenumber in unit of 1/Mpc
R	Input : smoothing scale in unit of Mpc

Returns

the window function

Here is the caller graph for this function:



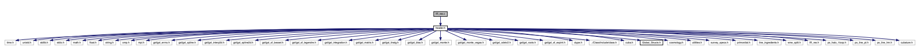
5.6.3 Variable Documentation

5.6.3.1 gb `struct globals gb`

5.7 IR_res.c File Reference

Documented IR_res module.

`#include "header.h"`
Include dependency graph for IR_res.c:



Functions

- double pm_IR_LO (struct Cosmology *Cx, double k, double z, long SPLIT)

  Compute the leading-order IR-resummed matter power spectrum, ala Ivanovic et al.
- double pm_IR_NLO (struct Cosmology *Cx, double k, double z, long SPLIT)

  Compute the next-to-leading-order IR-resummed matter power spectrum, ala Ivanovic et al.
- double IR_Sigma2_integrand (double x, void *par)

  Integrand to compute the suppression factor IR_sigma2.
- double IR_Sigma2 (struct Cosmology *Cx, double z, double kf0, long SPLIT)

  Compute the suppression factor IR_sigma2.
- double pm_nowiggle (struct Cosmology *Cx, double k, double z, double kf0, int cleanup, long SPLIT)

  Compute the no-wiggle componenet of the matter power spectrum.
- double pm_nowiggle_bspline (struct Cosmology *Cx, double k, double z, int cleanup)

  Compute the no-wiggle componenet of the matter power spectrum, reading in and interpolating the output of apython code which computed the broadband by fitting families of Bsplines (see Vlah et al 2015)
- double pm_nowiggle_gfilter (struct Cosmology *Cx, double k, double z, int cleanup)

  Compute the no-wiggle componenet of the matter power spectrum, using Gaussian filter (see Vlah et al 2015)
- double pm_nowiggle_dst (struct Cosmology *Cx, double k, double z, int cleanup)

  Compute the no-wiggle componenet of the matter power spectrum, reading in and interpolating the output of apython code which computed the broadband by discrete sin-transform, See Hamann et al 2010.

5.7.1 Detailed Description

Documented IR_res module.

Azadeh Moradinezhad Dizgah, November 4th 2021

This module is computes the leading and next-to-leading IR-resummed matter power spectrum The wiggle-nowiggle seperation is performed in wnw_split.c module.

In summary, the following functions can be called from other modules:

1. pm_IR_LO()
2. pm_IR_NLO()
3. IR_Sigma2()
4. pm_nowiggle()
5. pm_nowiggle_gfilter()
6. pm_nowiggle_bspline()
7. pm_nowiggle_dst()

5.7.2 Function Documentation

5.7.2.1 IR_Sigma2()

```
double IR_Sigma2 (
        struct Cosmology * Cx,
        double z,
        double kf0,
        long SPLIT )
```

Compute the suppression factor IR_sigma2.

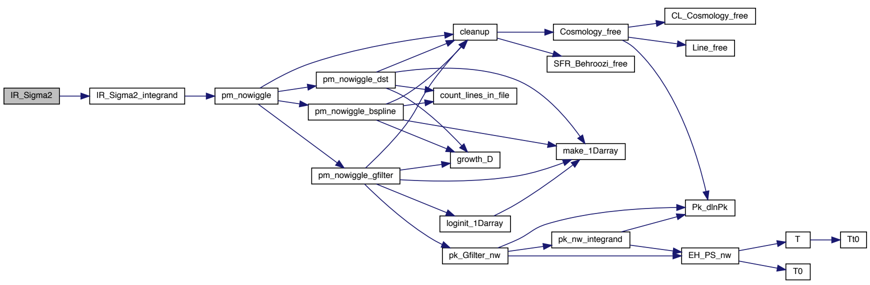
Parameters

Cx	Input↩: pointer to cosmology structure
z	Input↩: redshift
kf0	Input↩: first element of the k-array, used in normalization of EH no-wiggle spectrum
SPLIT	Input↩: switch to set the method of wiggle-nowiggle split

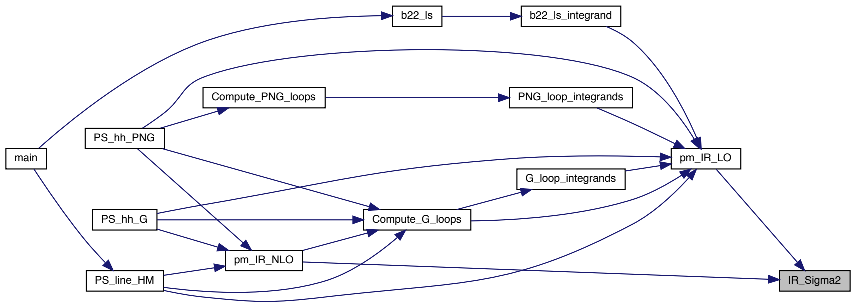
Returns

value of IR resummation suppression factor

Here is the call graph for this function:



Here is the caller graph for this function:



5.7.2.2 IR_Sigma2_integrand()

```
double IR_Sigma2_integrand (
        double x,
        void * par )
```

Integrand to compute the suppression factor IR_sigma2.

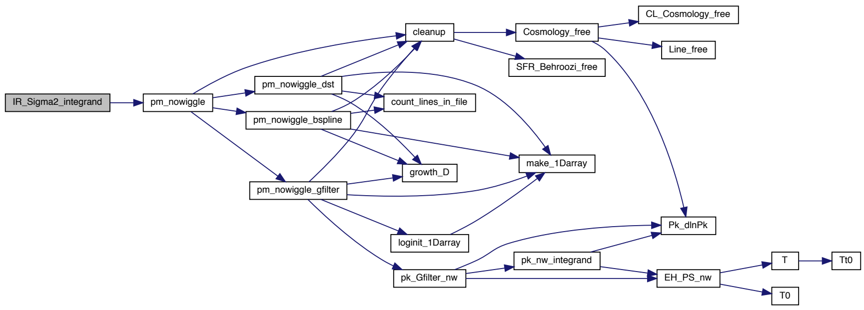
Parameters

x	Input↩ : integration variable, k-values
par	Input↩ : integration parameters

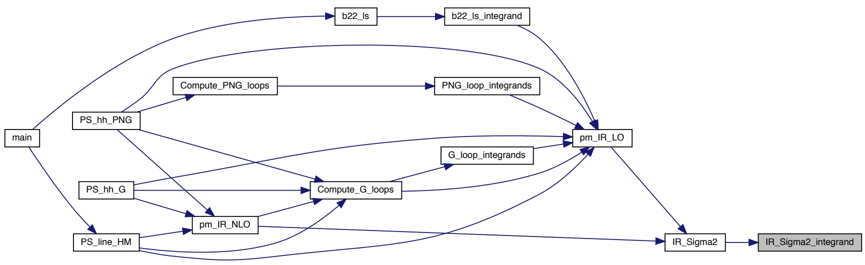
Returns

integrand to be used in IR_sigma2() function

BAO_scale = 110. Mpc/h.Here is the call graph for this function:



Here is the caller graph for this function:



5.7.2.3 pm_IR_LO()

```
double pm_IR_LO (
    struct Cosmology * Cx,
    double k,
    double z,
    long SPLIT )
```

Compute the leading-order IR-resummed matter power spectrum, ala Ivanovic et al.

Parameters

Cx	Input← : pointer to cosmology structure

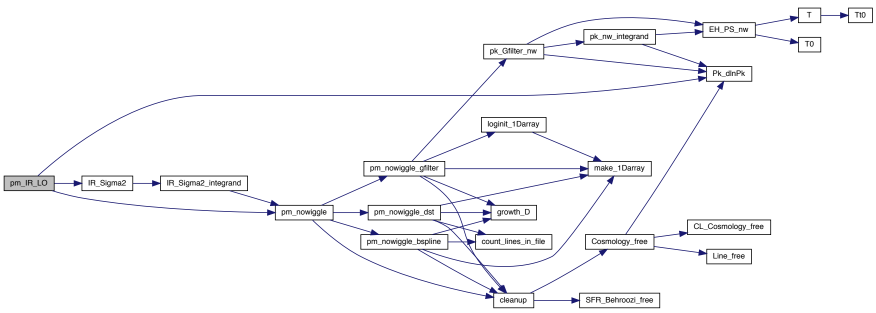
Parameters

k	Input : wavenumber in unit of 1/Mpc.
z	Input : redshift
SPLIT	Input : switch to set the method of wiggle-nowiggle split

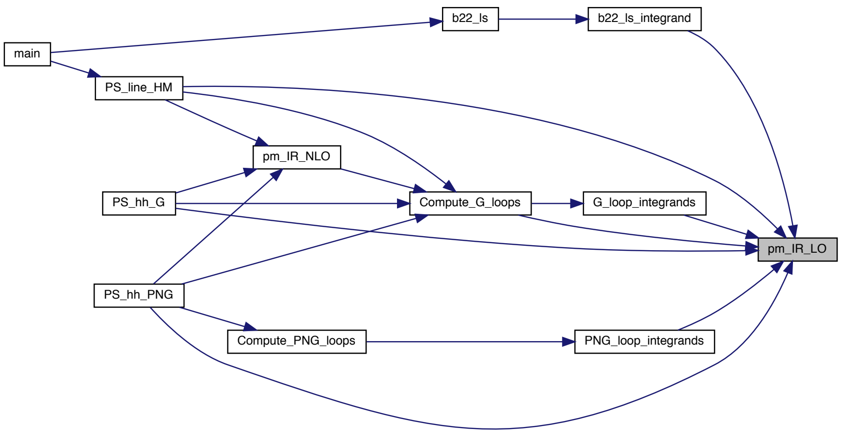
Returns

value of leading IR-ressumed power spectrum

Here is the call graph for this function:



Here is the caller graph for this function:



5.7.2.4 pm_IR_NLO()

```
double pm_IR_NLO (
    struct Cosmology * Cx,
    double k,
    double z,
    long SPLIT )
```

Compute the next-to-leading-order IR-resummed matter power spectrum, ala Ivanovic et al.

Parameters

Cx	Input: pointer to cosmology structure
k	Input: wavenumber in unit of 1/Mpc.
z	Input: redshift

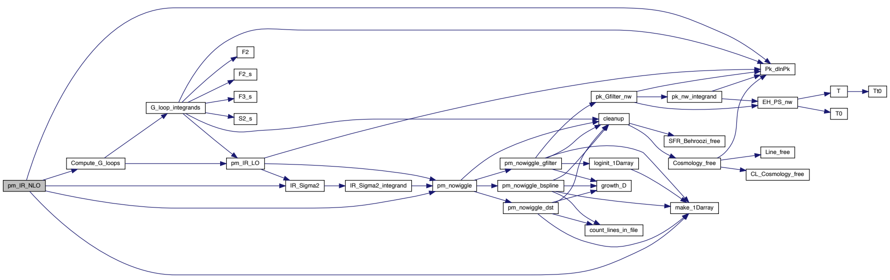
Parameters

SPLIT	Input← : switch to set the method of wiggle- nowiggle split

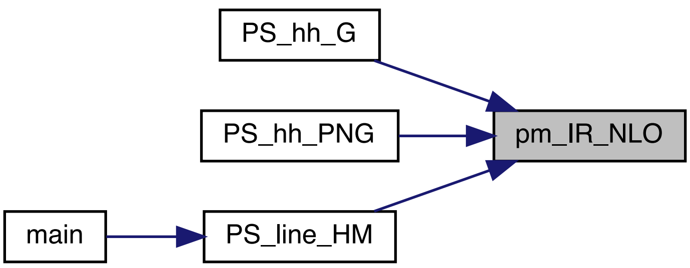
Returns

value of NL IR-ressumed power spectrum

Here is the call graph for this function:



Here is the caller graph for this function:



5.7.2.5 pm_nowiggle()

```
double pm_nowiggle (
        struct Cosmology * Cx,
        double k,
        double z,
        double kf0,
        int cleanup,
        long SPLIT )
```

Compute the no-wiggle componenet of the matter power spectrum.

Parameters

Cx	Input← : pointer to cosmology structure
k	Input← : wavenumber in unit of h/Mpc.
z	Input← : redshift
kf0	Input← : first element of the k-array, used in normalization of EH no-wiggle spectrum

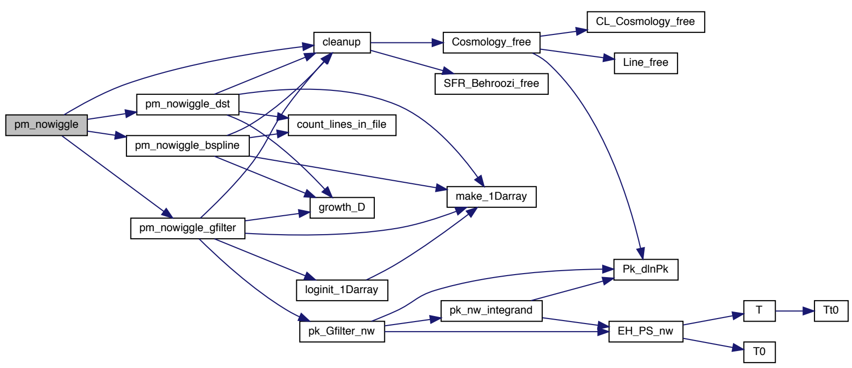
Parameters

cleanup	Input: switch to set whether to free the memory allocated to no-wiggle interpolators
SPLIT	Input: switch to set the method of wiggle-nowiggle split

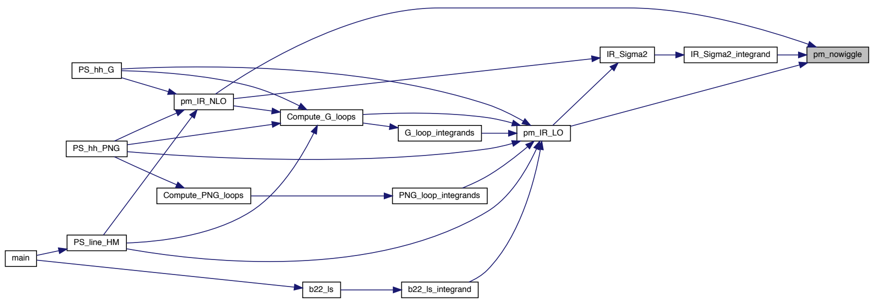
Returns

double value of no-wiggle power spectrum

Here is the call graph for this function:



Here is the caller graph for this function:



5.7.2.6 pm_nowiggle_bspline()

```
double pm_nowiggle_bspline (
    struct Cosmology * Cx,
    double k,
    double z,
    int cleanup )
```

Compute the no-wiggle componenet of the matter power spectrum, reading in and interpolating the output of apython code which computed the broadband by fitting families of Bsplines (see Vlah et al 2015)

Parameters

Cx	Input : pointer to cosmology structure
k	Input : wavenumber in unit of h/Mpc.
z	Input : redshift

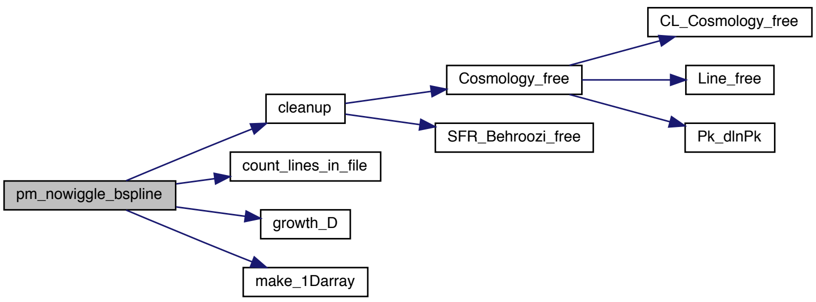
Parameters

cleanup	Input↩ : switch to set whether to free the memory allocated to no-wiggle interpolators

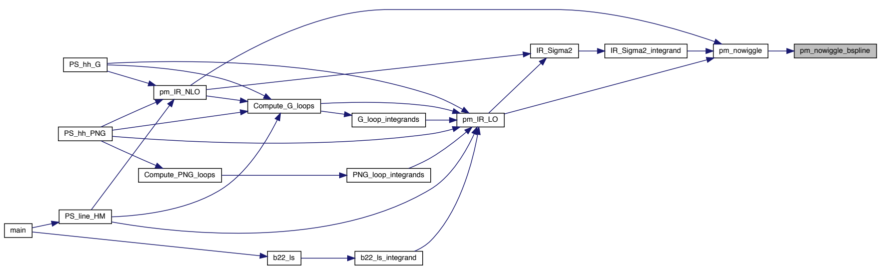
Returns

double value of no-wiggle power spectrum

Here is the call graph for this function:



Here is the caller graph for this function:



5.7.2.7 pm_nowiggle_dst()

```
double pm_nowiggle_dst (
    struct Cosmology * Cx,
    double k,
    double z,
    int cleanup )
```

Compute the no-wiggle componenet of the matter power spectrum, reading in and interpolating the output of apython code which computed the broadband by discrete sin-transform, See Hamann et al 2010.

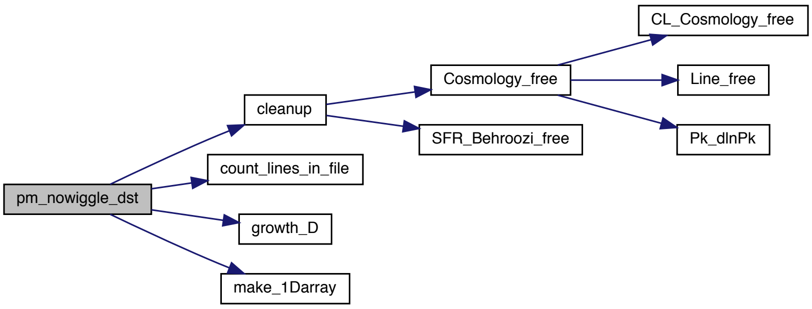
Parameters

Cx	Input : pointer to cosmology structure
k	Input : wavenumber in unit of h/Mpc.
z	Input : redshift
cleanup	Input : switch to set whether to free the memory allocated to no-wiggle interpolators

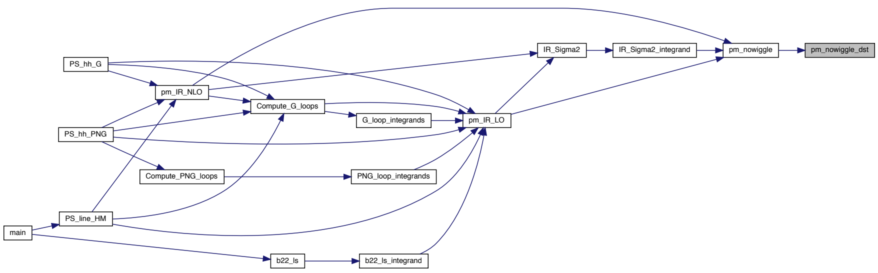
Returns

double value of no-wiggle power spectrum

Here is the call graph for this function:



Here is the caller graph for this function:



5.7.2.8 pm_nowiggle_gfilter()

```
double pm_nowiggle_gfilter (
        struct Cosmology * Cx,
        double k,
        double z,
        int cleanup )
```

Compute the no-wiggle componenet of the matter power spectrum, using Gaussian filter (see Vlah et al 2015)

Parameters

Cx	Input: pointer to cosmology structure

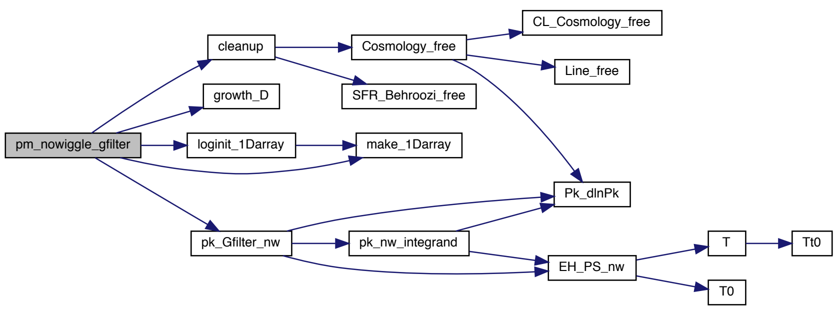
Parameters

k	Input↩ : wavenumber in unit of h/Mpc.
z	Input↩ : redshift
cleanup	Input↩ : switch to set whether to free the memory allocated to no-wiggle interpolators

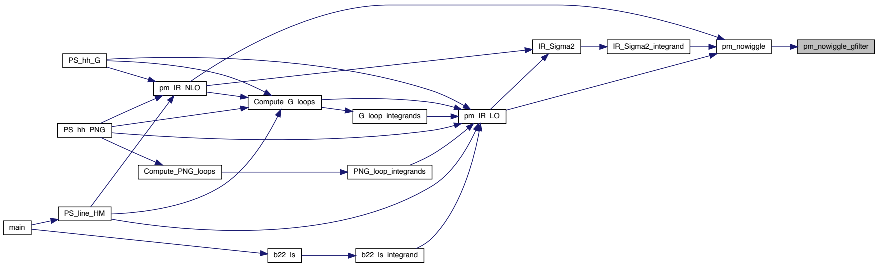
Returns

double value of no-wiggle power spectrum

Here is the call graph for this function:



Here is the caller graph for this function:

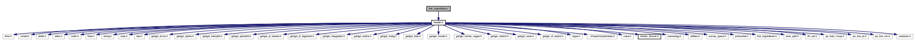


5.8 line_ingredients.c File Reference

Documented line_ingredients module.

```
#include "header.h"
```

Include dependency graph for line_ingredients.c:



Functions

- struct Line ∗ Line_alloc_init (struct Cosmology ∗Cx, long line_type, size_t npoints_interp, double M_min, long mode_mf)

    Allocate the memory and initialize the the line structure.
- int Line_free (struct Line ∗Lx)

    Free the line structure.
- int Line_evaluate (struct Line ∗Lx, double ∗zz, double ∗res)

    Allocate the memory and initialize the the line structure.
- double mult_func (double sigma, long mode_mf)

    Compute the multiplicity function needed to compute the halo mass function Three models are implemented: Press-Schechter, Sheth-Tormen and Tinker see Pillepich et al arxiv: 0811.4176 for the expressions.
- double mass_func (struct Cosmology ∗Cx, double M, double z, long mode_mf)

    Compute the halo mass function for Press-Schechter, Sheth-Tormen and Tinker models see Pillepich et al arxiv: 0811.4176 for the expressions.
- double mass_func_sims (struct Cosmology ∗Cx, double M, double z, long mode_mf)

    Read in the measured mass function of Hidden-valey sims and build an interpolator for HMF(M) for a fixed redshift.
- void halo_bias (struct Cosmology ∗Cx, double M, double z, long mode_mf, double ∗bias_arr)

    computes the halo biases for three mass functions, press-schecter, Sheth-Tormen, and Tinker mass functions
- void logSFR_Behroozi_read (double ∗z_arr, double ∗logM_arr, double ∗log10SFR)

    Read in the file for the star formation rate byy Behroozi et al 2013.
- int logSFR_alloc_init ()

    Allocate memory and initialize the 2d interpolator for the star formation rate of Behroozi et al 2013 as a function of halo mass and redshift.
- int SFR_Behroozi_free ()

    Free the memory allocated to the interpolators of star formation rate by Behroozi et al 2013.
- double logSFR_Behroozi (double logM, double z)

Evaluate the SFR interpolator object for a given value of mass and redshift.
- double luminosity (double M, double z, long mode_lum)

  Compute the line specific luminosity in unit of solar luminosity For CO ladder, I am using the fits in Table 4 of ??? et al arXiv:1508.05102, while for CII we use Silva et al arXiv:
- int mass_moment1_integ (unsigned nd, const double ∗x, void ∗p, unsigned fdim, double ∗fvalue)

  Compute the first luminosityy-weighted mass moment.
- double mass_moment1 (struct Cosmology ∗Cx, double z, double M_min, long mode_mf, long mode_lum)

  in unit of M_sun/Mpc^3
- int mass_moment2_integ (unsigned nd, const double ∗x, void ∗p, unsigned fdim, double ∗fvalue)

  Compute the second luminosityy-weighted mass moment.
- double mass_moment2 (struct Cosmology ∗Cx, double z, double M_min, long mode_mf, long mode_lum)

  in unit of M_sun/Mpc^3
- int bias_lum_weighted_integ (unsigned nd, const double ∗x, void ∗p, unsigned fdim, double ∗fvalue)

  Compute the luminosityy-weighted linear and quadratic line biases.
- void bias_lum_weighted (struct Cosmology ∗Cx, double z, double M_min, long mode_mf, long mode_lum, double ∗result)
- double p_sig_shot_integrand (double x, void ∗par)

  Model from Keating et al 2016 to account for the observed variation in halo activity, i.e.
- double p_sig_shot (double scatter)
- double p_sig_Tbar_integrand (double x, void ∗par)

  Model from Keating et al 2016 to account for the observed variation in halo activity, i.e.
- double p_sig_Tbar (double scatter)
- void line_bias (struct Line ∗Lx, double z, double ∗result)

  Compute the linear and quadratic line biases, accounting ffor the normalization w.r.t.
- double mean_intens (struct Cosmology ∗Cx, size_t line_id, double z)

  Compute the line mean intensity in unit of erg Mpc^-2 Sr^-1.
- double Tbar_line (struct Cosmology ∗Cx, size_t line_id, double z)

  Compute the mean brightness temprature of CO in unit of microK, compared with Pullen et al and Lidz et al 2011.

Variables

- struct globals gb

5.8.1 Detailed Description

Documented line_ingredients module.

This module includes functions that are needed for computing the line clustering and shot contributions.

Azadeh Moradinezhad Dizgah, November 4th 2021

In summary, the following functions can be called from other modules:

1. Line_alloc_init() allocate memory and initizlized the line structure which contains 4 interpolators for first and second mass moments and linear and quadratic line biases.
2. Line_free() frees the memory allocated to line structure
3. Line_evaluate() evaluates the interpolators initialized in Line_alloc_init()
4. mult_func() computes the multiplicity function needed for computing the halo mass function

5. mass_func() computes the halo mass finction. Three options are available, Press-Schecter, Sheth-Tormen, Tinker
6. mass_func_sims() reads in the measured mass function on Hidden-Valley simulations by Farnik, and convert it to compare with the theoretical predictions
7. halo_bias() computes the halo biases assuming the above theoretical predictions of the halo mass function
8. logSFR_Behroozi_read() reeds in the data file of Behroozi 2013 for SFR(M,z)
9. logSFR_alloc_init() allocates memory for 2d interpolator of logSFR(M,z)
10. SFR_behroozi_free() frees the memory allocated to logSFR interpolator
11. logSFR_Behroozi() evaluates the logSFR_Behroozi interpolator
12. luminosity() computes the line luminosity
13. mass_moment1() computes the first mass moment
14. mass_moment2() computes the first mass moment
15. bias_lum_weighted() computes the luminosity-weighetd line bias
16. p_sig_shot() computes the coefficient accounting for the scatter in L(M) in shot noise
17. p_sig_Tbar() computes the coefficient accounting for the scatter in L(M) in mean brightness temprature
18. mean_intens() compues the mean intensity of the line
19. Tbar_line() compues the mean brightness temprature of the line

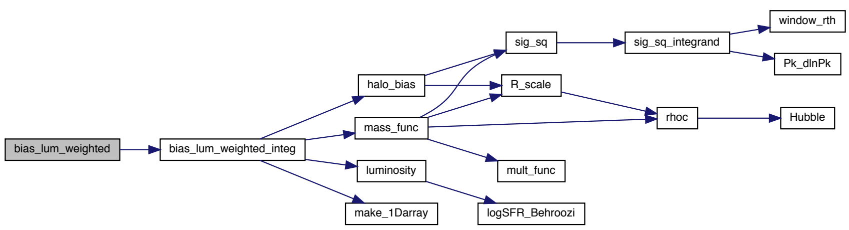
5.8.2 Function Documentation

5.8.2.1 bias_lum_weighted()

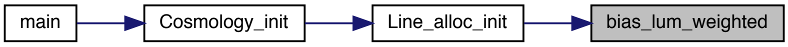
```
void bias_lum_weighted (
        struct Cosmology * Cx,
        double z,
        double M_min,
        long mode_mf,
        long mode_lum,
        double * result )
```

In units of solar mass;

In units of solar massHere is the call graph for this function:



Here is the caller graph for this function:



5.8.2.2 bias_lum_weighted_integ()

```
int bias_lum_weighted_integ (
        unsigned nd,
        const double * x,
        void * p,
        unsigned fdim,
        double * fvalue )
```

Compute the luminosityy-weighted linear and quadratic line biases.

The normalization of first mass moment is not included yet. The function bias_lum_weighted_integ() is the integrand and bias_lum_weighted() computes the bias

Parameters

Cx	Input: pointer to cosmology structure
z	Input: redshift
M_min	Input: minimum halo mass
mode_mf	Input: model of halo mass function to consider, PSC, ST, TR

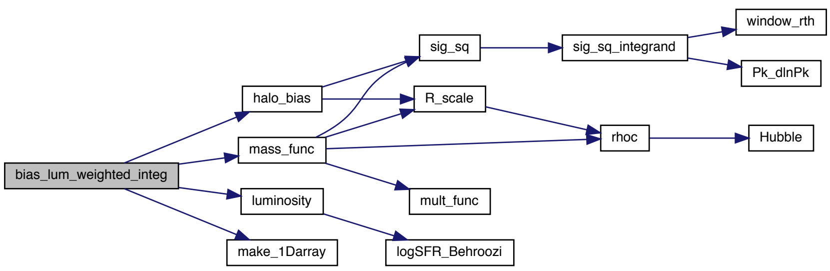
Parameters

mode_lum	Inpute← : which lumi- nosity model, basi- cally which line con- sid- ered

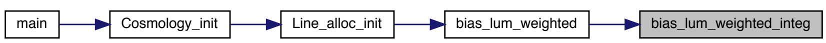
Returns

un-normalized line bias

Here is the call graph for this function:



Here is the caller graph for this function:



5.8.2.3 halo_bias()

```
void halo_bias (
        struct Cosmology * Cx,
        double M,
        double z,
        long mode_mf,
        double * bias_arr )
```

computes the halo biases for three mass functions, press-schecter, Sheth-Tormen, and Tinker mass functions

Parameters

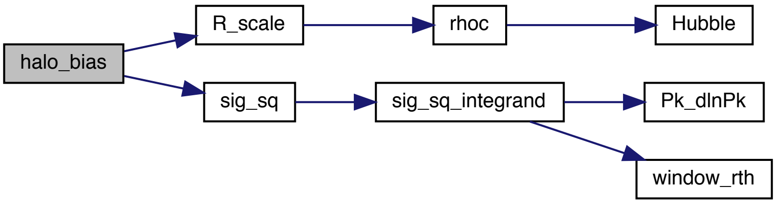
Cx	Input: Cosmology structure
M	Input: halo mass
z	Input: redshift
mode_mf	Input: switch for setting the model of mass function, can be set to PSC, ST, TR
bias_arr	Output: the output array containing linear and quadratic local-in-matter halo biases, and quadratic and cubic tidal biases

Returns

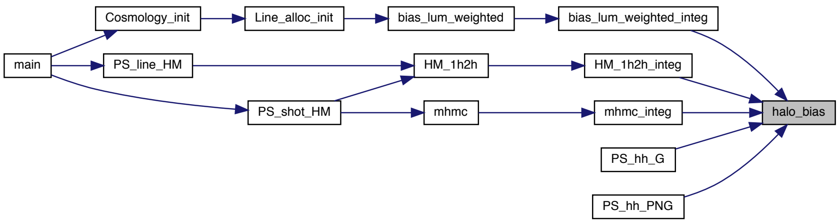
void

Note that for PSC and ST mass functions, same form of the biases can be assumed, with different coefficents. See astro-ph/0006319

Assuming spherical collapseHere is the call graph for this function:



Here is the caller graph for this function:



5.8.2.4 Line_alloc_init()

```
struct Line * Line_alloc_init (
        struct Cosmology * Cx,
        long line_type,
        size_t npoints_interp,
        double M_min,
        long mode_mf )
```

Allocate the memory and initialize the the line structure.

This structure contains interpolators for computing the luminosity-weighted mass moments and line biases For a given line defined with "line_type" variable, this function first computes the above four quantities for a wide range of redshifts. Next it iniialized 4 interpolators for these quantities, and store them in line structure.

Parameters

Cx	Input← : Cosmology struc- ture

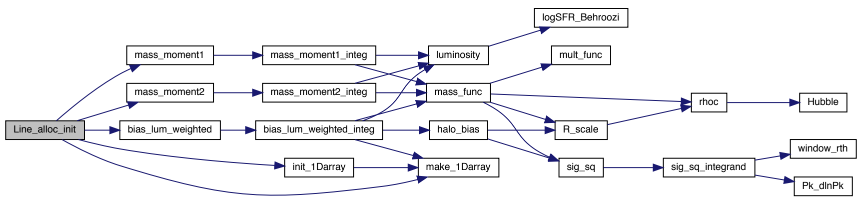
Parameters

line_type	Inpute↩ : name of the line to compute. It can be set to CII, CO10, CO21, CO32, CO43, CO54, CO65
npoints_interp	Input↩ : number of interpolation points
M_min	Input↩ : minimum halo mass for mass integrals
mode_mf	Inpute↩ : theoretical model of halo mass function to use. It can be set to sheth-↩ Tormen (ST), Tinker (TR) or Press-↩ Schecter (PSC)

Returns

the total clustering line power spectrum, including the 1- and 2-halo term

ClIHere is the call graph for this function:



Here is the caller graph for this function:

5.8.2.5 line_bias()

```
void line_bias (
    struct Line * Lx,
    double z,
    double * result )
```

Compute the linear and quadratic line biases, accounting ffor the normalization w.r.t.

the first mass moment

Parameters

Lx	Input↩ : Pointer to line structure
z	Input↩ : Redshift

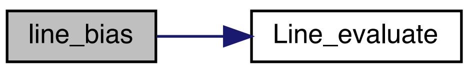
Parameters

result	Input: a pointer to an array containing the results of b1_line and b2_line

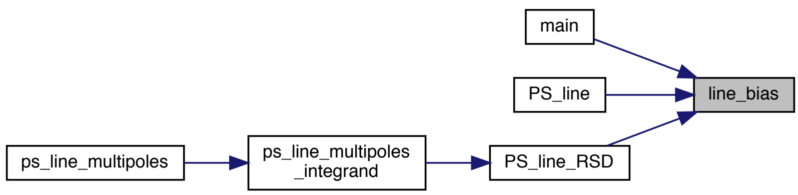
Returns

void

Here is the call graph for this function:



Here is the caller graph for this function:



5.8.2.6 Line_evaluate()

```
int Line_evaluate (
        struct Line * Lx,
        double * zz,
        double * res )
```

Allocate the memory and initialize the the line structure.

This structure contains interpolators for computing the luminosity-weighted mass moments and line biases For a given line defined with "line_type" variable, this function first computes the above four quantities for a wide range of redshifts. Next it iniialized 4 interpolators for these quantities, and store them in line structure.

Parameters

Lx	Input←↩ : Pointer to the line struc- ture

Parameters

zz	Input: this is an array with 4 elements to determine which of the 4 interpolators should be evaluated. • If any of the elements are set to DO_NOT_EVALUATE, the quantitiy corresponding to that index is not computed. O • If any of the elements

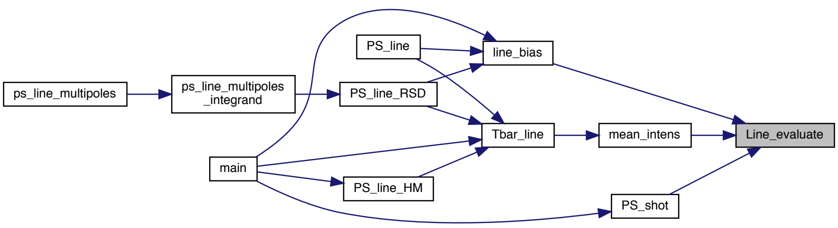
Parameters

res	Output: an array containing the results. The number of elements of this array depends on how the zz array is set.

Returns

the error status

Here is the caller graph for this function:



5.8.2.7 Line_free()

```
int Line_free (
    struct Line * Lx )
```

Free the line structure.

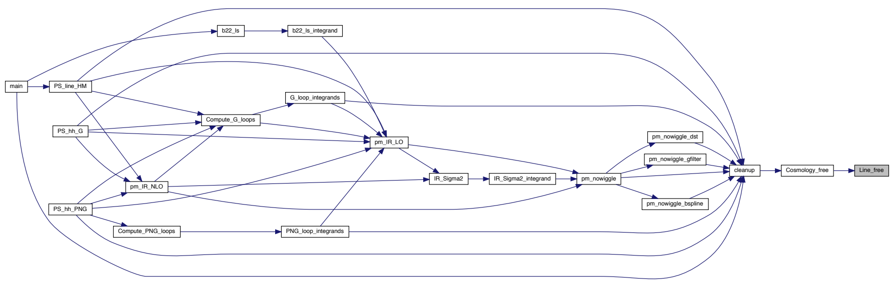
Parameters

Lx	Input: Pointer to line structure

Returns

the error status

Here is the caller graph for this function:



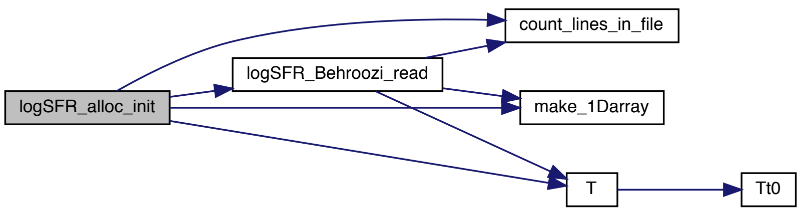
5.8.2.8 logSFR_alloc_init() `int logSFR_alloc_init ( )`

Allocate memory and initialize the 2d interpolator for the star formation rate of Behroozi et al 2013 as a function of halo mass and redshift.

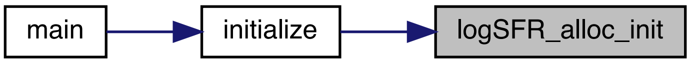
Returns

the error status

Here is the call graph for this function:



Here is the caller graph for this function:



5.8.2.9 logSFR_Behroozi() `double logSFR_Behroozi (`

```
double logM,
double z )
```

Evaluate the SFR interpolator object for a given value of mass and redshift.

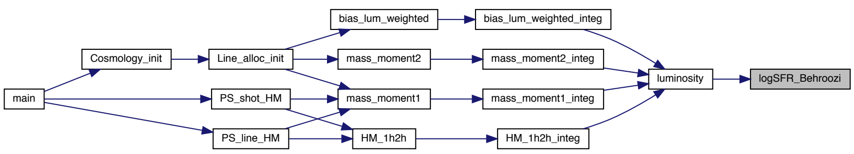
Parameters

logM	Input←↩ : log10 of halo mass
z	Input←↩ : red-shift

Returns

log10SFR

Here is the caller graph for this function:



5.8.2.10 logSFR_Behroozi_read() `void logSFR_Behroozi_read (`

```
double * z_arr,
double * logM_arr,
double * log10SFR )
```

Read in the file for the star formation rate byy Behroozi et al 2013.

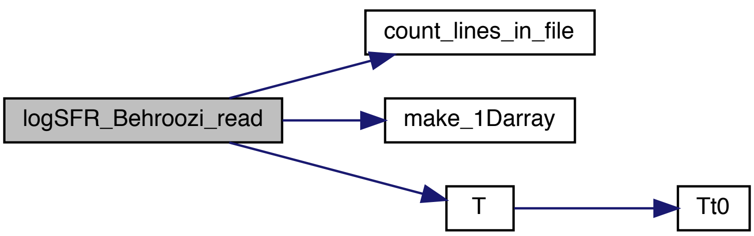
Parameters

z_arr	Output↩ : pointer to an array of red-shifts read from the file
logM_arr	Output↩ : pointer to an array of halo masses read from the file
log10SFR	Output↩ : pointer to an array of SFR read from the file

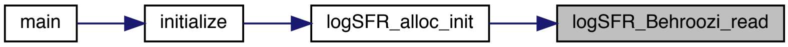
Returns

void

Here is the call graph for this function:



Here is the caller graph for this function:



5.8.2.11 luminosity()

```
double luminosity (
    double M,
    double z,
    long mode_lum )
```

Compute the line specific luminosity in unit of solar luminosity For CO ladder, I am using the fits in Table 4 of ??? et al arXiv:1508.05102, while for CII we use Silva et al arXiv:

Parameters

M	Input: halo mass
z	Input: redshift
mode_lum	Inpute: which luminosity model, basically which line considered

Returns

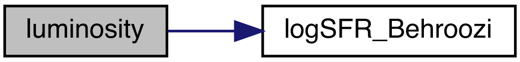
line luminosity

a = 1.37 Charilli

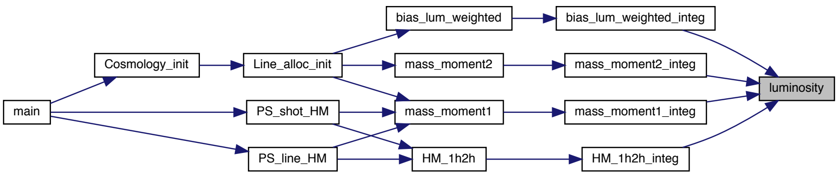
b = -1.74

in unit of K km/s pc^2

in unit of L_sunHere is the call graph for this function:



Here is the caller graph for this function:



5.8.2.12 mass_func()

```
double mass_func (
    struct Cosmology * Cx,
    double M,
    double z,
    long mode_mf )
```

Compute the halo mass function for Press-Schechter, Sheth-Tormen and Tinker models see Pillepich et al arxiv: 0811.4176 for the expressions.

Parameters

Cx	Input↩ : Cosmology structure
M	Input↩ : Halo mass function
z	Input↩ : redshift

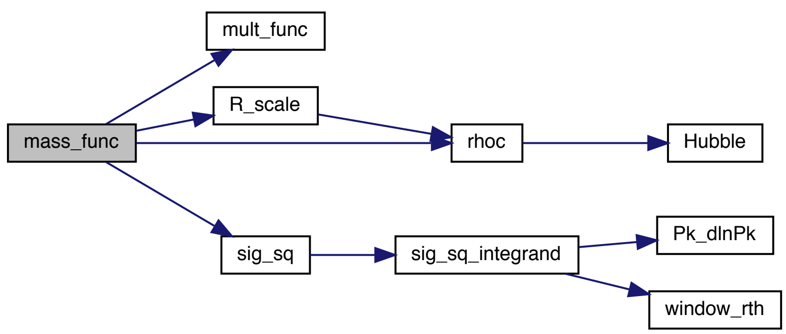
Parameters

mode_mf	Input↩ : switch for setting the model of mass function, can be set to PSC, ST, TR

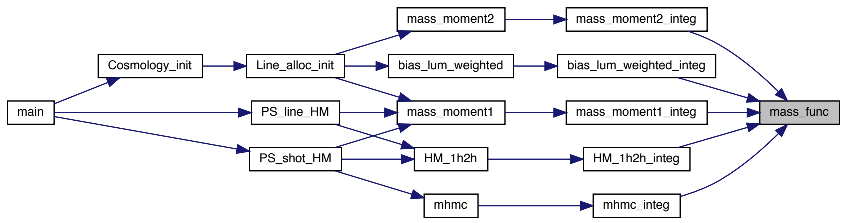
Returns

the halo mass function in unit of halos per Mpc^3 per solar mass, compared at z=0 with Murray etal https↩ ://arxiv.org/abs/1306.5140

Here is the call graph for this function:



Here is the caller graph for this function:



5.8.2.13 mass_func_sims()

```
double mass_func_sims (
    struct Cosmology * Cx,
    double M,
    double z,
    long mode_mf )
```

Read in the measured mass function of Hidden-valey sims and build an interpolator for HMF(M) for a fixed redshift.

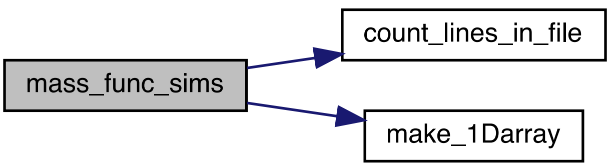
Parameters

Cx	Input : Cosmology structure
M	Input : halo mass
z	Input : redshift
mode_mf	Input : switch for setting the model of mass function, can be set to PSC, ST, TR

Returns

the interpolated measured halo mass function
M in unit of M_sun and HMF in unit of #-of-halos/Mpc^3/M_sun

Here is the call graph for this function:



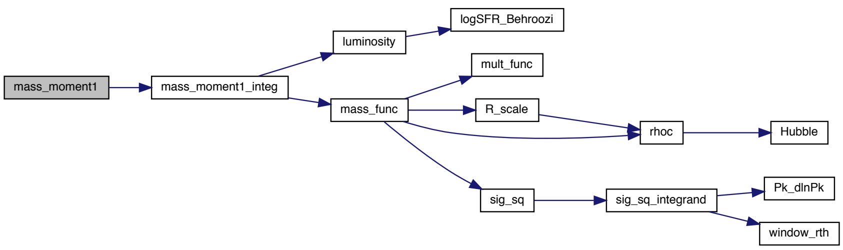
5.8.2.14 mass_moment1()

```
double mass_moment1 (
        struct Cosmology * Cx,
        double z,
        double M_min,
        long mode_mf,
        long mode_lum )
```

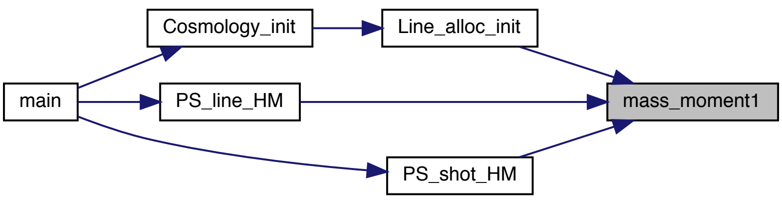
in unit of M_sun/Mpc^3

In units of solar mass;

In units of solar massHere is the call graph for this function:



Here is the caller graph for this function:



5.8.2.15 mass_moment1_integ()

```
int mass_moment1_integ (
        unsigned nd,
        const double * x,
        void * p,
        unsigned fdim,
        double * fvalue )
```

Compute the first luminosityy-weighted mass moment.

The function mass_moment1_integ() is the integrand and mass_moment1() compute the moment

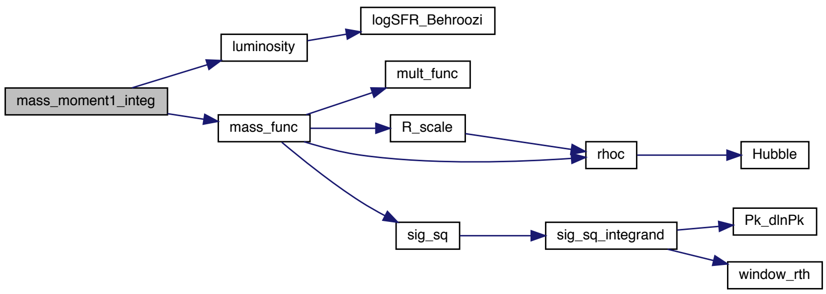
Parameters

Cx	Input← : pointer to cosmology structure
z	Input← : redshift
M_min	Input← : minimum halo mass
mode_mf	Input← : model of halo mass function to consider, PSC, ST, TR
mode_lum	Inpute← : which luminosity model, basically which line considered

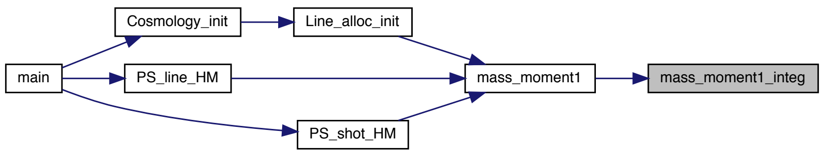
Returns

the first mass moment

Here is the call graph for this function:



Here is the caller graph for this function:



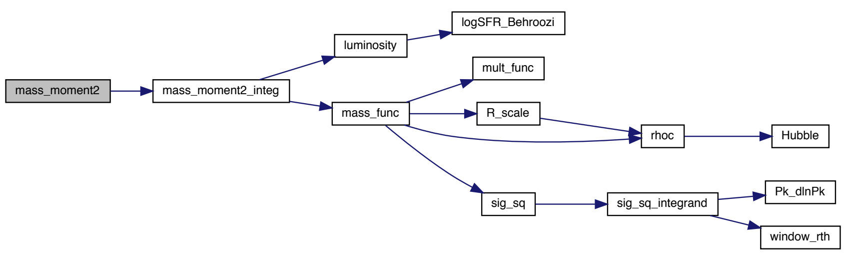
5.8.2.16 mass_moment2()

```
double mass_moment2 (
    struct Cosmology * Cx,
    double z,
    double M_min,
    long mode_mf,
    long mode_lum )
```

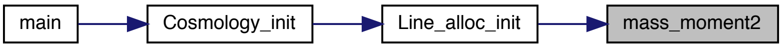
in unit of M_sun/Mpc^3

In units of solar mass;

In units of solar massHere is the call graph for this function:



Here is the caller graph for this function:



5.8.2.17 mass_moment2_integ()

```
int mass_moment2_integ (
    unsigned nd,
    const double * x,
    void * p,
    unsigned fdim,
    double * fvalue )
```

Compute the second luminosityy-weighted mass moment.

The function mass_moment2_integ() is the integrand and mass_moment2() compute the moment

Parameters

Cx	Input↩ : pointer to cosmology structure
z	Input↩ : redshift
M_min	Input↩ : minimum halo mass
mode_mf	Input↩ : model of halo mass function to consider, PSC, ST, TR

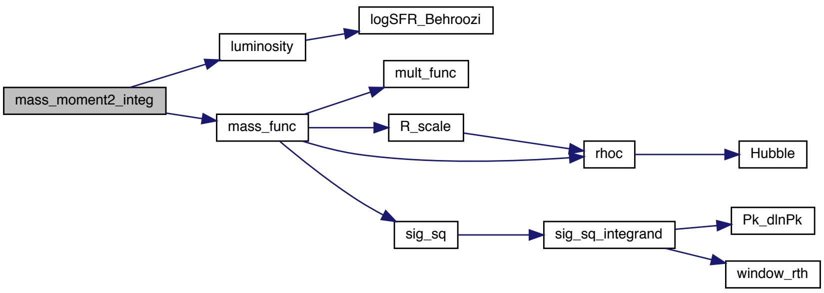
Parameters

mode_lum	Inpute↩ : which luminosity model, basically which line considered

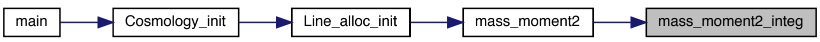
Returns

the second mass moment

Here is the call graph for this function:



Here is the caller graph for this function:



5.8.2.18 mean_intens()

```
double mean_intens (
    struct Cosmology * Cx,
    size_t line_id,
    double z )
```

Compute the line mean intensity in unit of erg Mpc^-2 Sr^-1.

Parameters

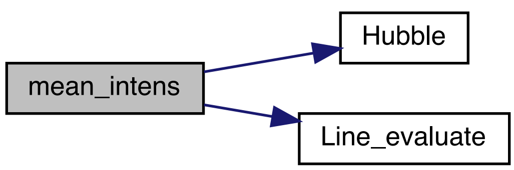
Cx	Input← : Pointer to cosmology structure
line_id	Inpute← : id of line of interest, an integer value
z	Input← : Redshift

Returns

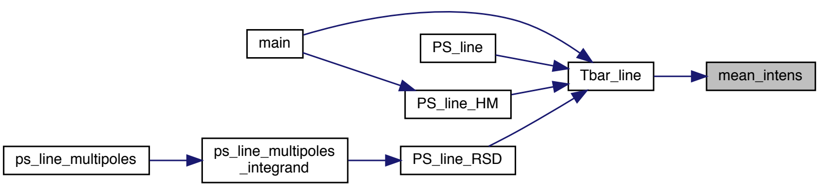
the line mean intensity

Note: nu_J is the rest-frame emission frequency related to the observed frequency as nu_obs = nu_J/(1+z_J) For a CO transition from J-> J-1, the rest-frame frequency is nu_J = J nu_CO where nu_Co = 115 GHz.

in unit of erg/sHere is the call graph for this function:



Here is the caller graph for this function:



5.8.2.19 mult_func()

```
double mult_func (
    double sigma,
    long mode_mf )
```

Compute the multiplicity function needed to compute the halo mass function Three models are implemented: Press-Schechter, Sheth-Tormen and Tinker see Pillepich et al arxiv: 0811.4176 for the expressions.

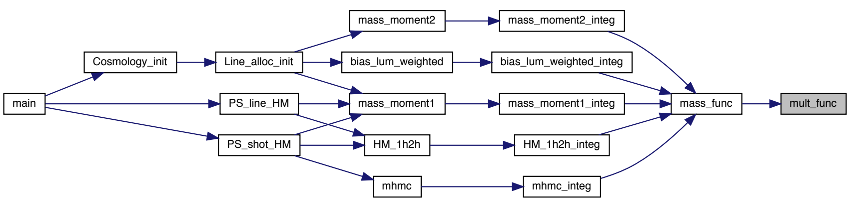
Parameters

sigma	Input↵ : variance of matter fluctuations
mode_mf	Input↵ : switch for setting the model of mass function, can be set to PSC, ST, TR

Returns

the multiplicity function

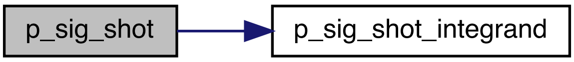
In Barkana & Loeb Rev a = 0.75Here is the caller graph for this function:



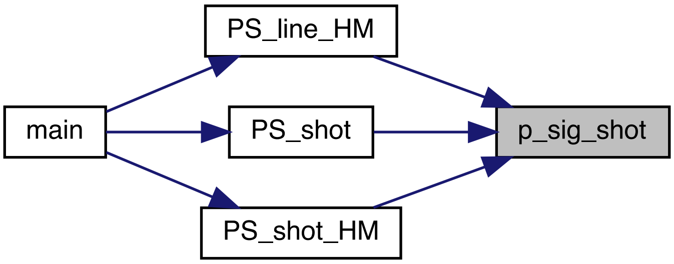
5.8.2.20 p_sig_shot()

```
double p_sig_shot (
    double scatter )
```

Here is the call graph for this function:



Here is the caller graph for this function:



5.8.2.21 p_sig_shot_integrand()

```
double p_sig_shot_integrand (
    double x,
    void * par )
```

Model from Keating et al 2016 to account for the observed variation in halo activity, i.e.

scatter in the L(M) relation p_sig_shot replaces the f_duty in the shot-noise used in some LIM paper (ex. Lidz et al 2011). p_sig_shot_integrand() is the integrand, and p_sig_shot() computes the scatter factor for the shot noise.

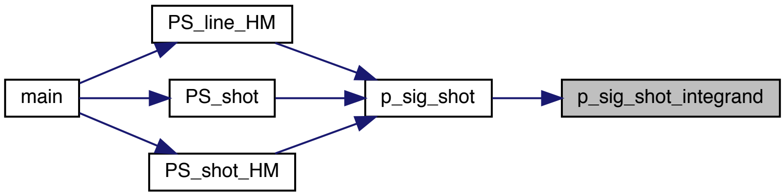
Parameters

scatter	Input: variance of the log-scatter

Returns

the scatter coeff of the shot noise

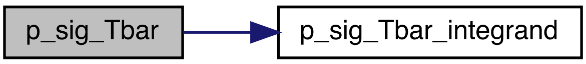
Here is the caller graph for this function:



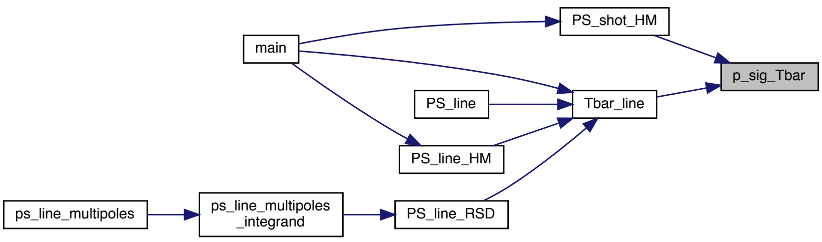
5.8.2.22 p_sig_Tbar()

```
double p_sig_Tbar (
    double scatter )
```

Here is the call graph for this function:



Here is the caller graph for this function:



5.8.2.23 p_sig_Tbar_integrand()

```
double p_sig_Tbar_integrand (
    double x,
    void * par )
```

Model from Keating et al 2016 to account for the observed variation in halo activity, i.e.

scatter in the L(M) relation p_sig_Tbar replace the f_duty in the average brightness temprature used in some LIM paper (ex. Lidz et al 2011). p_sig_Tbar_integrand() is the integrand, and p_sig_Tbar() computes the scatter factor for the mean brightness temprature.

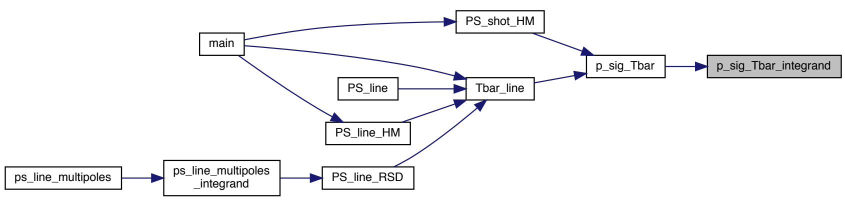
Parameters

scatter	Input: variance of the log-scatter

Returns

the scatter coeff of Tbar

Here is the caller graph for this function:



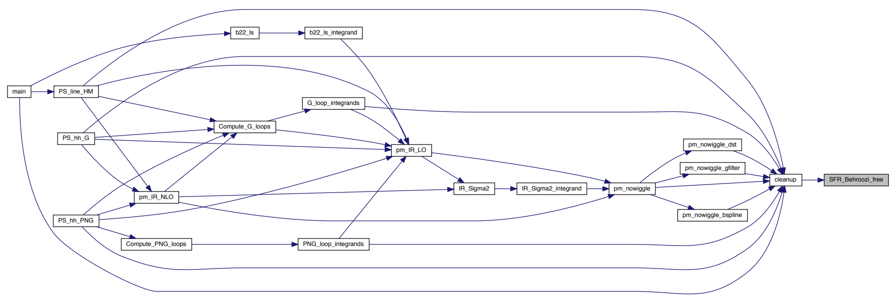
5.8.2.24 SFR_Behroozi_free() `int SFR_Behroozi_free ( )`

Free the memory allocated to the interpolators of star formation rate by Behroozi et al 2013.

Returns

the error status

Here is the caller graph for this function:



5.8.2.25 Tbar_line()

```
double Tbar_line (
        struct Cosmology * Cx,
        size_t line_id,
        double z )
```

Compute the mean brightness temprature of CO in unit of microK, compared with Pullen et al and Lidz et al 2011.

Parameters

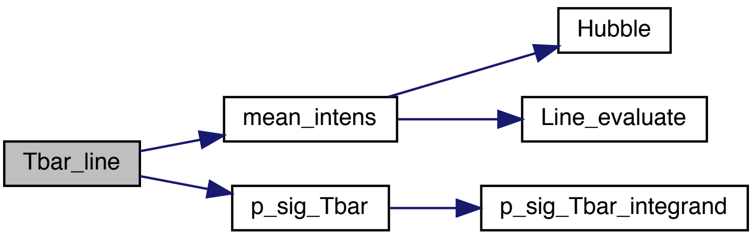
Cx	Input← : Pointer to cosmology structure
line_id	Inpute← : id of line of interest, an integer value
z	Input← : Redshift

Returns

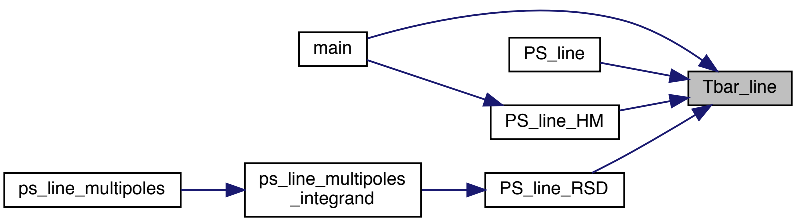
the line mean temprature assuming Rayleigh-Jeans limit

Boltzmann constant in unit of erg K^-1

factor of 10^6 is the conversion factor from K to microKHere is the call graph for this function:



Here is the caller graph for this function:



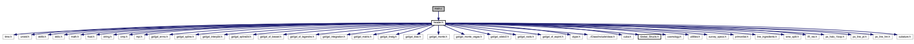
5.8.3 Variable Documentation

5.8.3.1 gb `struct globals gb`

5.9 main.c File Reference

Documented main module, including functions to initilize and cleanup the cosmology structure and examples of calls to functions in other modules to compute the line clustering and shot power spectrum.

`#include "header.h"`
Include dependency graph for main.c:



Functions

- int main (int argc, char ∗argv[ ])
- void initialize ()

  Initizlize the path to the required directories, set the values of cosmological parmaeters, and initialize the interpolator of the SFR(M,z) from tabulated data provided in gb.SFR_filename.
- void cleanup (struct Cosmology ∗Cx)

  Free the memory allocated to cosmology structure and SFR interpolator.

Variables

- struct globals gb

5.9.1 Detailed Description

Documented main module, including functions to initilize and cleanup the cosmology structure and examples of calls to functions in other modules to compute the line clustering and shot power spectrum.

Azadeh Moradinezhad Dizgah, November 4th 2021

In order to call any function from the package, the function calls should be placed in the marked section of main() function.

5.9.2 Function Documentation

5.9.2.1 cleanup()

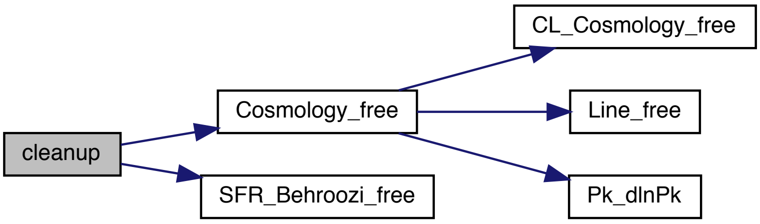
```
void cleanup (
        struct Cosmology * Cx )
```

Free the memory allocated to cosmology structure and SFR interpolator.

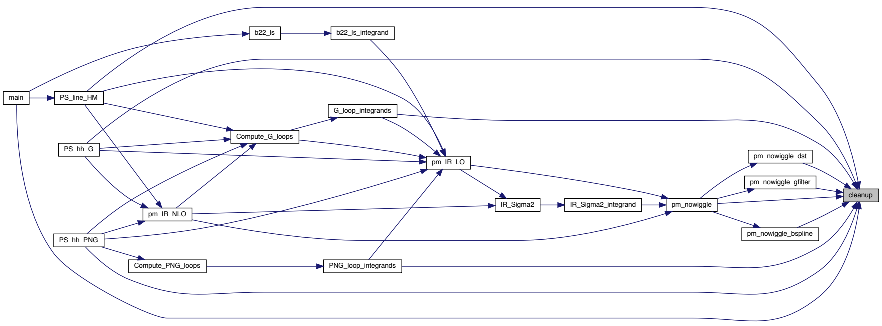
Returns

void

Here is the call graph for this function:



Here is the caller graph for this function:



5.9.2.2 initialize()

```
void initialize ( )
```

Initizlize the path to the required directories, set the values of cosmological parmaeters, and initialize the interpolator of the SFR(M,z) from tabulated data provided in gb.SFR_filename.

List of limHaloPT header files.

The global structure "gb" have several elements to hold the paths to project source directory, input, and output folders, and values of cosmological parmaeters.

Returns

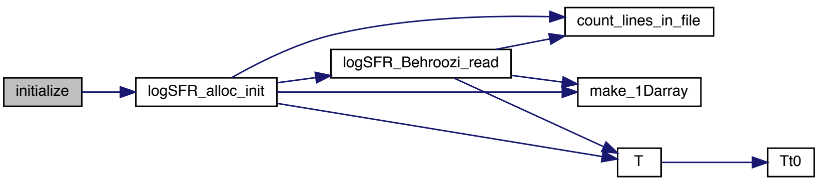
void

Change the path to the parent directory

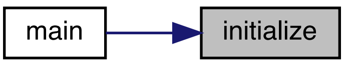
In units of km/s

omega_b = Omega_b h^2;

3.0665Here is the call graph for this function:



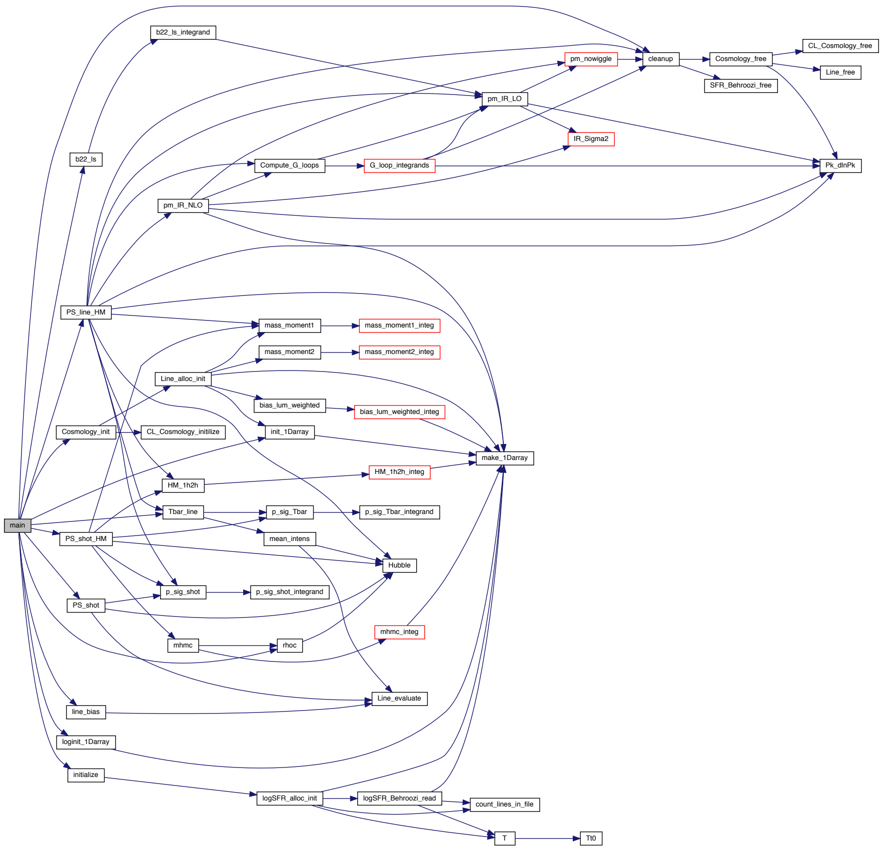
Here is the caller graph for this function:



5.9.2.3 main()

```
int main (
    int argc,
    char * argv[] )
```

Here is the call graph for this function:



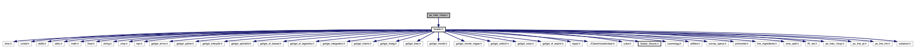
5.9.3 Variable Documentation

5.9.3.1 gb `struct globals gb`

5.10 ps_halo_1loop.c File Reference

Documented real-space, direct integration computation of 1loop contributions of the halo/galaxy power spectrum See arXiv:2010.14523 for explicit expressions.

`#include "header.h"`
Include dependency graph for ps_halo_1loop.c:



Functions

- double PS_hh_G (struct Cosmology ∗Cx, double k, double z, double M, long mode_pt, long IR_switch, long SPLIT, long mode_mf)

  Compute the contributions up to 1loop to halo power spectrum for Gaussian initial conditions.
- double PS_hh_PNG (struct Cosmology ∗Cx, double k, double z, double M, long mode_pt, long IR_switch, long SPLIT, long mode_mf)

  Compute contributions up to 1loop to halo power spectrum arising from non-Gaussian initial conditions of local shape.
- void Compute_G_loops (struct Cosmology ∗Cx, double k, double z, long IR_switch, long hm_switch, long SPLIT, double ∗result)

  Compute the loop contributions dure to nonlinear evolution of matter fluctuations and nonlinear halo bias, present for Gaussian initial conditions The function G_loop_integrands() defines the integrand and Compute_G_loops() computes the integrals.
- static int G_loop_integrands (const int ∗ndim, const cubareal x[ ], const int ∗ncomp, cubareal ff[ ], void ∗p)
- void Compute_PNG_loops (struct Cosmology ∗Cx, double k, double z, long IR_switch, long SPLIT, double ∗result)

  Compute the loop contributions dure to nonlinear evolution of matter fluctuations and nonlinear halo bias, rising from non-Gaussian initial conditions of local shape The function PNG_loop_integrands() defines the integrand and Compute_PNG_loops() computes the integrals.
- static int PNG_loop_integrands (const int ∗ndim, const cubareal x[ ], const int ∗ncomp, cubareal ff[ ], void ∗p)
- double F2_s (double k1, double k2, double mu)
- double S2_s (double k1, double k2, double mu)
- double F3_s (double k, double q, double mu)
- double S2 (double mu)
- double F2 (double k1, double k2, double mu)

Variables

- struct globals gb

5.10.1 Detailed Description

Documented real-space, direct integration computation of 1loop contributions of the halo/galaxy power spectrum See arXiv:2010.14523 for explicit expressions.

Azadeh Moradinezhad Dizgah, November 4th 2021

This module computes the 1loop halo/galaxy power sprtcurm in real-space via direct numerical integration. IR-resummation and EFT counter terms are included. In addition to loops due to gravitational loops, terms arising only in the presence of local PNG are also included. The explicit expressions of all the loops are given in 2010.14523.

In summary, the following functions can be called from other modules:

1. PS_hh_G()
2. PS_hh_PNG()
3. Compute_Gloops()
4. Compute_PNGloops()
5. F2_s()
6. F3_s()
7. S2_s()
8. F2()
9. S2()

5.10.2 Function Documentation

5.10.2.1 Compute_G_loops()

```
void Compute_G_loops (
    struct Cosmology * Cx,
    double k,
    double z,
    long IR_switch,
    long hm_switch,
    long SPLIT,
    double * result )
```

Compute the loop contributions dure to nonlinear evolution of matter fluctuations and nonlinear halo bias, present for Gaussian initial conditions The function G_loop_integrands() defines the integrand and Compute_G_loops() computes the integrals.

Parameters

Cx	Input↩ : pointer to cosmology structure
k	Input↩ : wavenumber
z	Input↩ : redshift of interest
M	Input↩ : halo mass, used in computing the halo bias
IR_switch	Input↩ : switch to decide whether to perform IR resummation or no

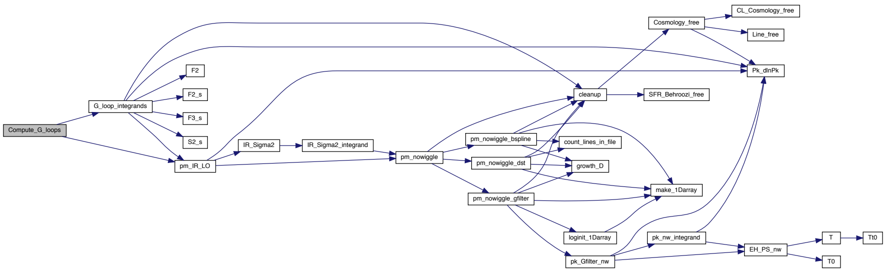
Parameters

hm_switch	Input : switch to decide whether to compute the 1loop terms due to matter or bias
SPLIT	Input : switch to set the method to perform the wiggle-nowiggle split of matter power spectrum
result	Output : an output array containing the results of the 1loop terms, has 2 elements for hm_switch=MATTER, and 6 elements for hm_switch=HALO

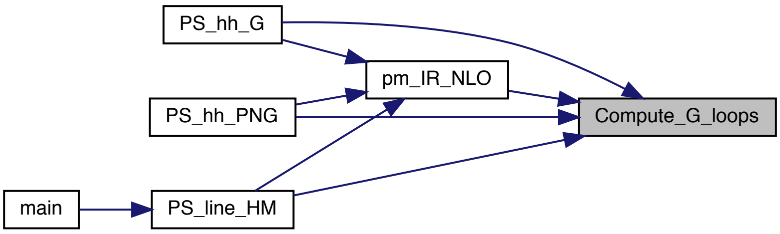
Returns

void

Here is the call graph for this function:



Here is the caller graph for this function:



5.10.2.2 Compute_PNG_loops()

```
void Compute_PNG_loops (
        struct Cosmology * Cx,
        double k,
        double z,
        long IR_switch,
        long SPLIT,
        double * result )
```

Compute the loop contributions dure to nonlinear evolution of matter fluctuations and nonlinear halo bias, rising from non-Gaussian initial conditions of local shape The function PNG_loop_integrands() defines the integrand and Compute_PNG_loops() computes the integrals.

Parameters

Cx	Input← : pointer to cosmology structure
k	Input← : wavenumber
z	Input← : redshift of interest
IR_switch	Input← : switch to decide whether to perform IR resummation or no
SPLIT	Input← : switch to set the method to perform the wiggle-nowiggle split of matter power spectrum

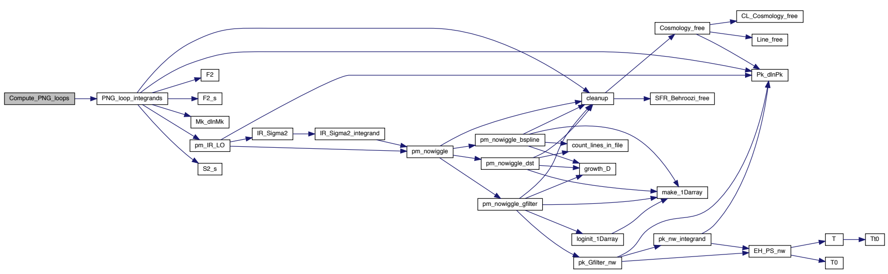
Parameters

result	Output: an output array containing the results of the 1loop terms, has 8 elements for hm_switch=HALO

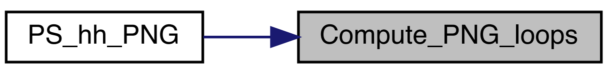
Returns

void

Here is the call graph for this function:

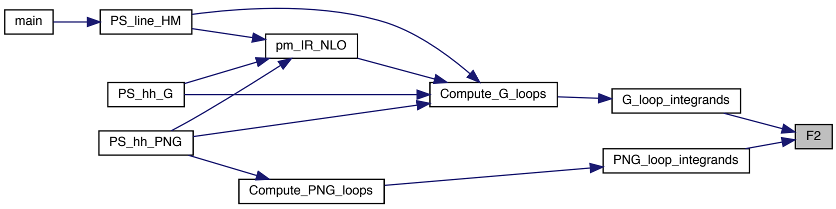


Here is the caller graph for this function:



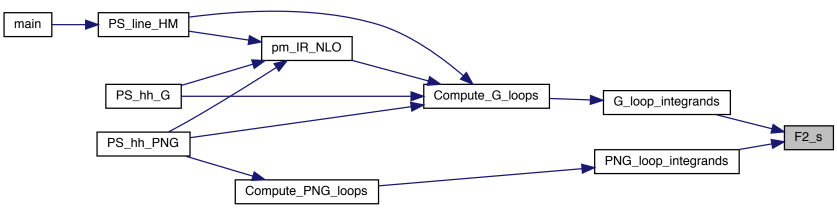
5.10.2.3 F2() double F2 (
double *k1*,
double *k2*,
double *mu*)

Here is the caller graph for this function:



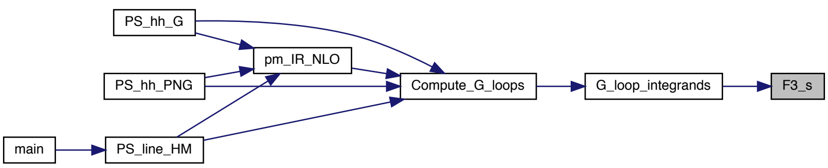
5.10.2.4 F2_s() double F2_s (
double *k1*,
double *k2*,
double *mu*)

Here is the caller graph for this function:



5.10.2.5 F3_s() double F3_s (
double *k*,
double *q*,
double *mu*)

Here is the caller graph for this function:

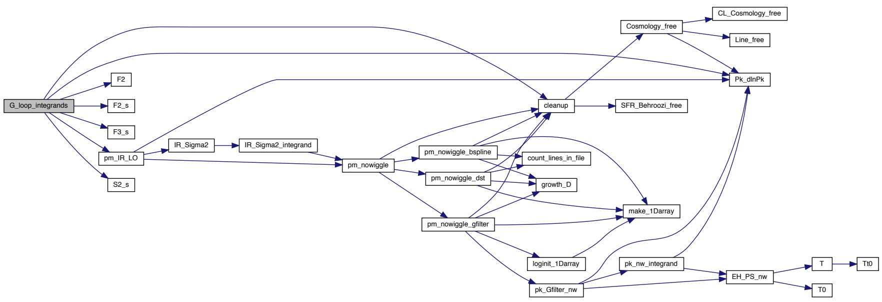


5.10.2.6 G_loop_integrands() static int G_loop_integrands (

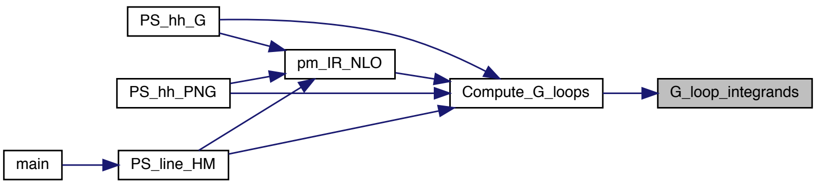
```
const int * ndim,
const cubareal x[],
const int * ncomp,
cubareal ff[],
void * p )  [static]
```

Model used in 1907.06666, the integrals are given in the appendix, Eq. A1, note that my S2_s = sigma^2(q,k-1) and F2_s = F2(q,k-q) in their notation. Factor of 2. ∗ (logqmax - logqmin) is due to change of variable from 0 to logarithmic k, and a factor of 2∗PI is due to integration over azimuthal angle. Note that to compare the theoretical predictions against Emiliano's measurement, since he is using a different notation for Fourier transform, I need to devide each 0 power spectrum by a factor of 1/pow(2.∗M_PI,3.), which I do in my pk_lin() function. If using another notation for Fourier transform (the one that I usually use, which has a factor of 1/pow(2∗M_PI,3) in the definition), you need to multiply these integrands by a factor of 1/pow(2∗M_PI,3).

The integrands below correspond to the follwing bias combinaions:Here is the call graph for this function:



Here is the caller graph for this function:



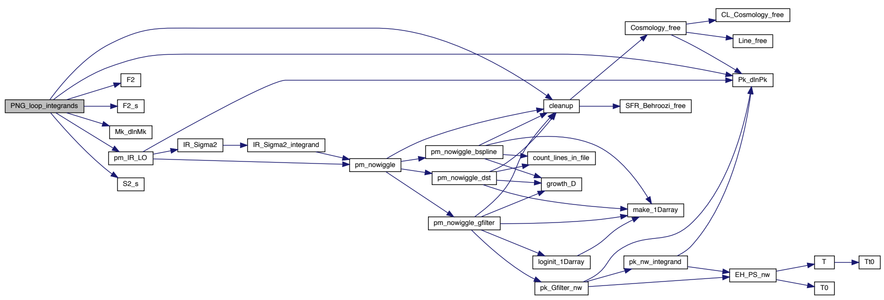
5.10.2.7 PNG_loop_integrands() static int PNG_loop_integrands (

```
const int * ndim,
const cubareal x[],
const int * ncomp,
cubareal ff[],
void * p )  [static]
```

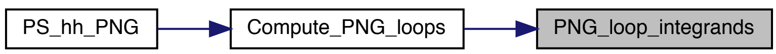
Factor of 2. ∗ (logqmax - logqmin) is due to change of variable from 0 to logarithmic k, and a factor of 2∗PI is due to integration over azimuthal angle. Note that to compare the theoretical predictions against Emiliano's measurement, since he is using a different notation for Fourier transform, I need to devide each 0 power spectrum by a factor of

1/pow(2.∗M_PI,3.), which I do in my pk_lin() function. If using another notation for Fourier transform (the one that I usually use, which has a factor of 1/pow(2∗M_PI,3) in the definition), you need to multiply these integrands by a factor of 1/pow(2∗M_PI,3).

The integrands below correspond to the follwing bias combinaions:Here is the call graph for this function:



Here is the caller graph for this function:



5.10.2.8 PS_hh_G()

```
double PS_hh_G (
        struct Cosmology * Cx,
        double k,
        double z,
        double M,
        long mode_pt,
        long IR_switch,
        long SPLIT,
        long mode_mf )
```

Compute the contributions up to 1loop to halo power spectrum for Gaussian initial conditions.

Parameters

Cx	Input : pointer to cosmology structure
k	Input : wavenumber

Parameters

z	Input← : redshift of interest
M	Input← : halo mass, used in computing the halo bias
mode_pt	Input← : switch to decide whether to compute tree-level halo power spectrum or the 1loop
IR_switch	Input← : switch to decide whether to perform IR resummation or no

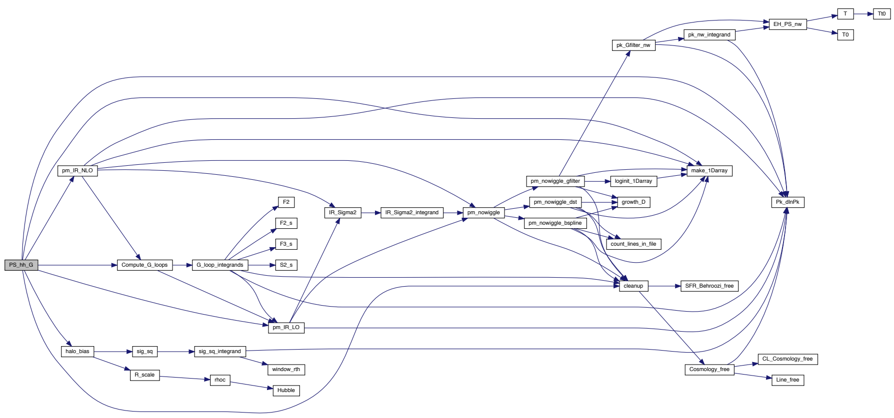
Parameters

SPLIT	Input↩ : switch to set the method to perform the wiggle-nowiggle split of matter power spectrum
mode_mf	Input↩ : switch to set the theoretical model of the mass function used to compute the halo biases

Returns

G loop contributions of P_h

Here is the call graph for this function:



5.10.2.9 PS_hh_PNG()

```
double PS_hh_PNG (
    struct Cosmology * Cx,
    double k,
    double z,
    double M,
    long mode_pt,
    long IR_switch,
    long SPLIT,
    long mode_mf )
```

Compute contributions up to 1loop to halo power spectrum arising from non-Gaussian initial conditions of local shape.

Parameters

Cx	Input↩ : pointer to cosmology structure
k	Input↩ : wavenumber
z	Input↩ : redshift of interest
M	Input↩ : halo mass, used in computing the halo bias

Parameters

mode_pt	Input↩ : switch to decide whether to compute tree-level halo power spectrum or the 1loop
IR_switch	Input↩ : switch to decide whether to perform IR resummation or no
SPLIT	Input↩ : switch to set the method to perform the wiggle-nowiggle split of matter power spectrum

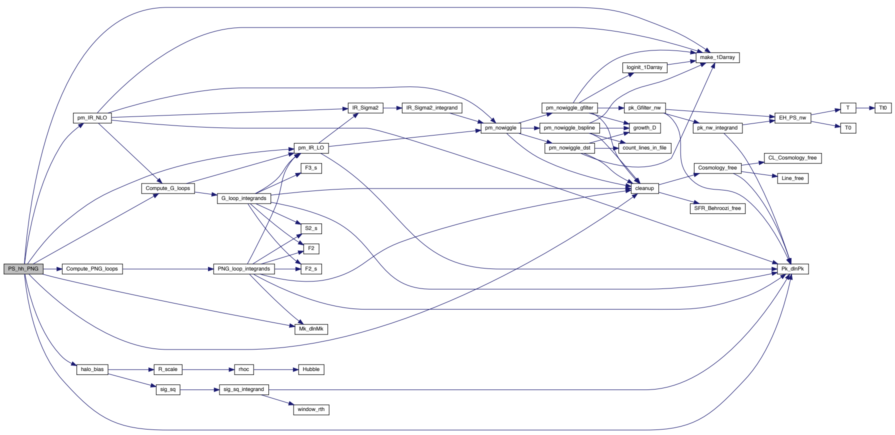
Parameters

mode_mf	Input↩ : switch to set the theoretical model of the mass function used to compute the halo biases

Returns

PNG loop contributions of P_h

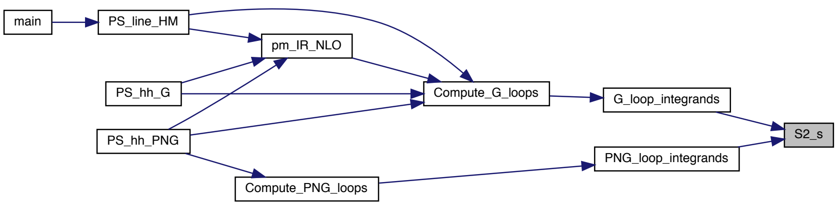
Here is the call graph for this function:



5.10.2.10 S2() `double S2 ( double mu )`

5.10.2.11 S2_s() `double S2_s ( double k1, double k2, double mu )`

Here is the caller graph for this function:



5.10.3 Variable Documentation

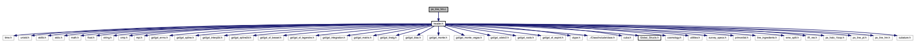
5.10.3.1 gb `struct globals gb`

5.11 ps_line_hm.c File Reference

Documented halo-model computation of line power spectrum, including clustering and stochastic contributions beyond Poisson limit.

`#include "header.h"`

Include dependency graph for ps_line_hm.c:



Functions

- double PS_line_HM (struct Cosmology ∗Cx, double k, double z, double M_min, long mode_mf, long line_type, int line_id)

  Compute the clustering contribution to the line power spectrum using halo-model.
- double PS_shot_HM (struct Cosmology ∗Cx, double k, double z, double M_min, double ∗input, long mode←_mf, long line_type)

  Compute the shot noise contributions, including corrections beyond poisson limit (see 1706.08738 for more details) If nfw=1, the dependance of the power spectrum on the halo profile is neglected.
- static int mhmc_integ (const int ∗ndim, const cubareal x[ ], const int ∗ncomp, cubareal ff[ ], void ∗p)

  Compute the corrections to mass integration of HM matter power spectrum.
- void mhmc (struct Cosmology ∗Cx, double z, long mode_mf, double ∗result)
- static int HM_1h2h_integ (const int ∗ndim, const cubareal x[ ], const int ∗ncomp, cubareal ff[ ], void ∗p)

  Compute the mass integrals to compute the 1- and 1-halo line, line-matter and matter power spectrum If nfw=1, the dependance of the power spectrum on the halo profile is neglected.
- void HM_1h2h (struct Cosmology ∗Cx, double k, double z, double M_min, long mode_mf, long line_type, long mode_hm, double ∗result)

  in unit of M_sun/Mpc^3
- static int b22_ls_integrand (const int ∗ndim, const cubareal x[ ], const int ∗ncomp, cubareal ff[ ], void ∗p)

  Compute the large-scale limit of P_b2b2 loop.
- double b22_ls (struct Cosmology ∗Cx, double z)

Variables

- struct globals gb

5.11.1 Detailed Description

Documented halo-model computation of line power spectrum, including clustering and stochastic contributions beyond Poisson limit.

Azadeh Moradinezhad Dizgah, November 4th 2021

This module has two main functions:

- PS_line_HM() to compute clustering (1- and 2-halo terms). The 2-halo term, includes nonlinear corrections to halo power spectrum arising from nonlinearities of matter fluctuations and halo biases.
- PS_shot_HM() to compute the stochastic contrubutions beyond Poisson shot noise (see arXiv:1706.08738)

The other functions in these modules are utilities for computing the above two main functions.

In summary, the following functions can be called from other modules:

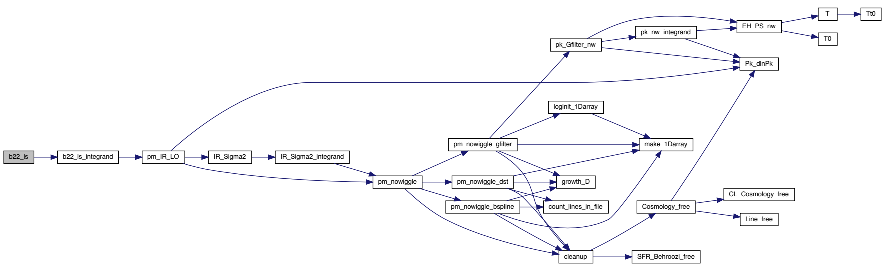
1. PS_line_HM()
2. PS_shot_HM()
3. mhmc() computes th corrections to mass integration of halo-model matter power spectrum
4. HM_1h2h() performs the mass integraks for computing 1- and 2-halo terms of line-line, line-matter and matter-matter power spectra.
5. b22_ls() computes the large-scale limit of P_b2b2 loop which behaves like a constant and so contributes to the shot noise.

5.11.2 Function Documentation

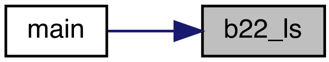
5.11.2.1 b22_ls()

```
double b22_ls (
        struct Cosmology * Cx,
        double z )
```

Here is the call graph for this function:



Here is the caller graph for this function:



5.11.2.2 b22_ls_integrand()

```
static int b22_ls_integrand (
        const int * ndim,
        const cubareal x[],
        const int * ncomp,
        cubareal ff[],
        void * p ) [static]
```

Compute the large-scale limit of P_b2b2 loop.

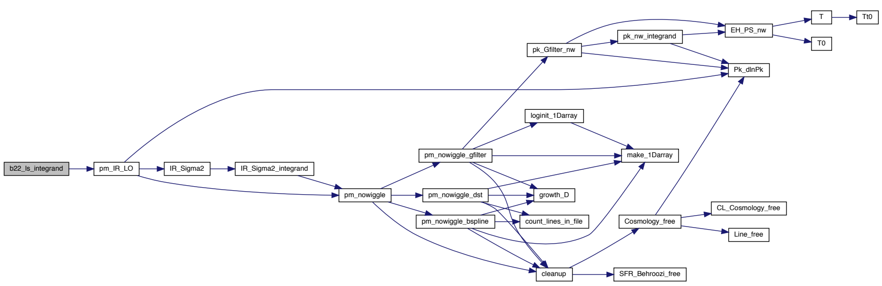
Parameters

Cx	Input : Cosmology structure
z	Input : redshift

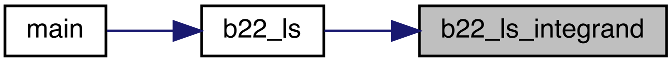
Returns

b22_ls

Here is the call graph for this function:



Here is the caller graph for this function:

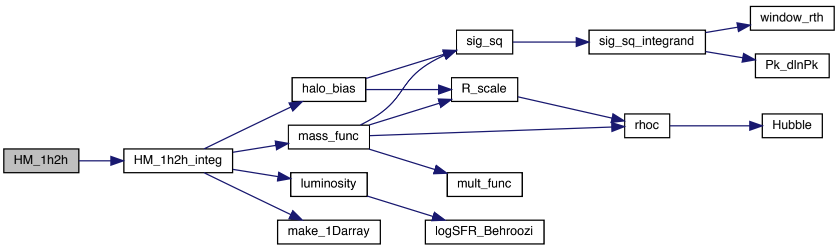


5.11.2.3 HM_1h2h()

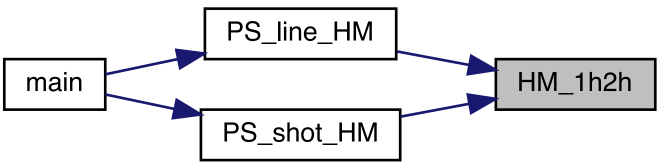
```
void HM_1h2h (
    struct Cosmology * Cx,
    double k,
    double z,
    double M_min,
    long mode_mf,
    long line_type,
    long mode_hm,
    double * result )
```

in unit of M_sun/Mpc^3

Here is the call graph for this function:



Here is the caller graph for this function:



5.11.2.4 HM_1h2h_integ()

```
static int HM_1h2h_integ (
    const int * ndim,
    const cubareal x[],
    const int * ncomp,
    cubareal ff[],
    void * p ) [static]
```

Compute the mass integrals to compute the 1- and 1-halo line, line-matter and matter power spectrum If nfw=1, the dependance of the power spectrum on the halo profile is neglected.

Otherwise, NFW halo profile is assumed

Parameters

Cx	Input: Cosmology structure
k	Input: wavenumber in unit of 1/Mpc.
z	Input: redshift
M_min	Input: minimum halo mass for mass integrals
mode_mf	Input: theoretical model of halo mass function to use. It can be set to sheth-Tormen (ST), Tinker (TR) or Press-Schecter (PSC)

Parameters

line_type	Input : name of the line to compute. It can be set to CII, CO10, CO21, CO32, CO43, CO54, CO65

Parameters

mode_hm	Input: a switch to decide whetehr to compute gthe mass integrations. It can be set to: • LINE for line power spectrum, • LINEMATTER for line-matter cross spectrum • MATTER for matter power spectrum

Parameters

results	Output↩ : anarray of the integration results. Number of elements varies depending on mode↩ _hm switch↩ : • 3 elements if mode↩ _↩ hm = LINE, • 1 element if mode↩ _↩ hm = LINEMATTER • 2 element if mode↩ _↩ hm = MATTER esults[0]↩ : correction

Parameters

Returns

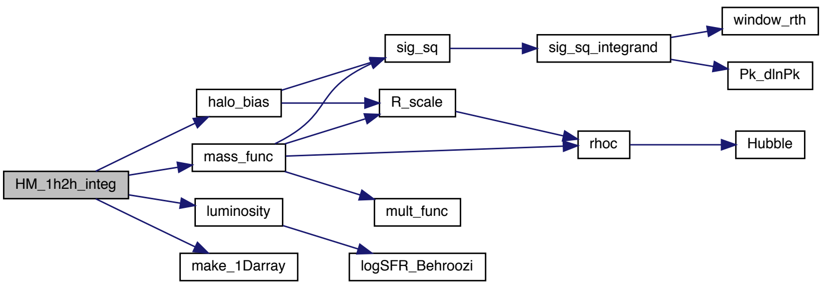
void

we assume the profile of both matter and line are NFW

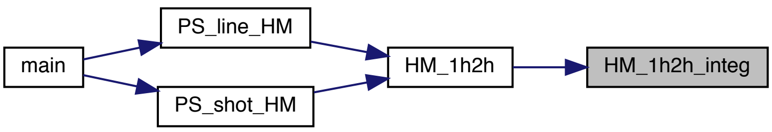
integrand of line 1halo term

integrand of 2halo term proportional to b1, the linear local-in-matter halo bias

integrand of 1halo term of line-matter cross-spectrumHere is the call graph for this function:



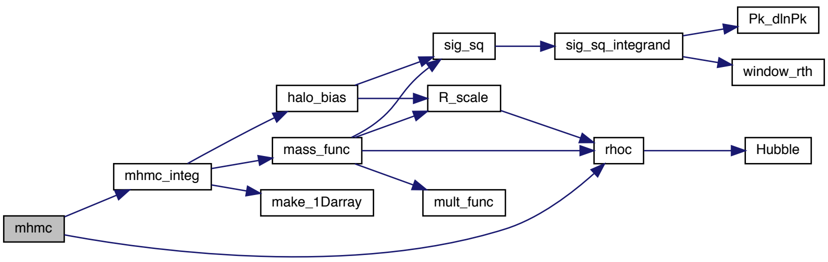
Here is the caller graph for this function:



5.11.2.5 mhmc()

```
void mhmc (
        struct Cosmology * Cx,
        double z,
        long mode_mf,
        double * result )
```

Here is the call graph for this function:



Here is the caller graph for this function:

5.11.2.6 mhmc_integ()

```
static int mhmc_integ (
    const int * ndim,
    const cubareal x[ ],
    const int * ncomp,
    cubareal ff[ ],
    void * p ) [static]
```

Compute the corrections to mass integration of HM matter power spectrum.

The function mhmc_integ() defines the integrand to be used by Cuhre integration routine of CUBA library. mhmc() returns the corrections to 1- and 2-halo terms performing the integration

When computing the matter power spectrum using halo-model, the mass integrations for 1- and 2-loop terms get contributions from halos of all masses. For numerical computation, we need to impose a lower and upper integration limit. While the result of the integration are not sensitive to the upper bound (due to the fact that the mass function drops rapidly at high M_h) the choice of the lower bound affects the results. We can compute the leading order corrections to the integral that are accurate up to (k R_s)^2. (see App. A of arXiv:1511.02231 for more details.)

Parameters

Cx	Input: Cosmology structure

Parameters

z	Input↩ : redshift
mode_mf	Inpute↩ : theoretical model of halo mass function to use. It can be set to Press-↩ Schecter (PSC), sheth-↩ Tormen (ST), Tinker (TR)

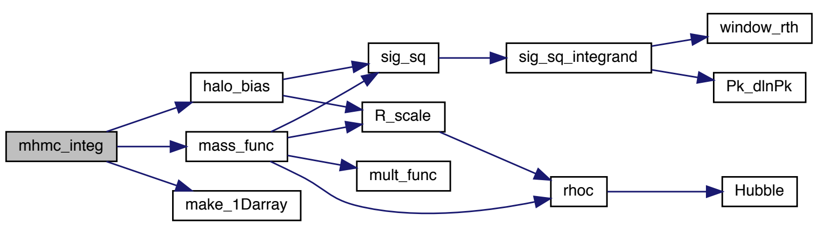
Parameters

results	Output↩ : a 2d array of the integration results, • results[0]↩ : correction to 1-halo term, • result[1]↩ : correcrions to 2-halo term assuming linear halo bias

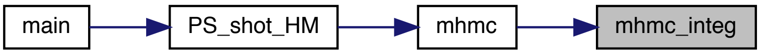
Returns

void

Here is the call graph for this function:



Here is the caller graph for this function:



5.11.2.7 PS_line_HM()

```
double PS_line_HM (
    struct Cosmology * Cx,
    double k,
    double z,
    double M_min,
    long mode_mf,
    long line_type,
    int line_id )
```

Compute the clustering contribution to the line power spectrum using halo-model.

If nfw=1, the dependance of the power spectrum on the halo profile is neglected. Otherwise, NFW halo profile is assumed

Parameters

Cx	Input↩ : pointer to Cosmology structure
k	Input↩ : wavenumber in unit of 1/Mpc.
z	Input↩ : redshift
M_min	Input↩ : minimum halo mass for mass integrals

Parameters

mode_mf	Inpute↩ : theoretical model of halo mass function to use. It can be set to sheth-↩ Tormen (ST), Tinker (TR) or Press-↩ Schecter (PSC)
line_type	Inpute↩ : name of the line to compute. It can be set to CII, CO10, CO21, CO32, CO43, CO54, CO65
line_id	Inpute↩ : id of the line to be considered.

Returns

P_clust(k)

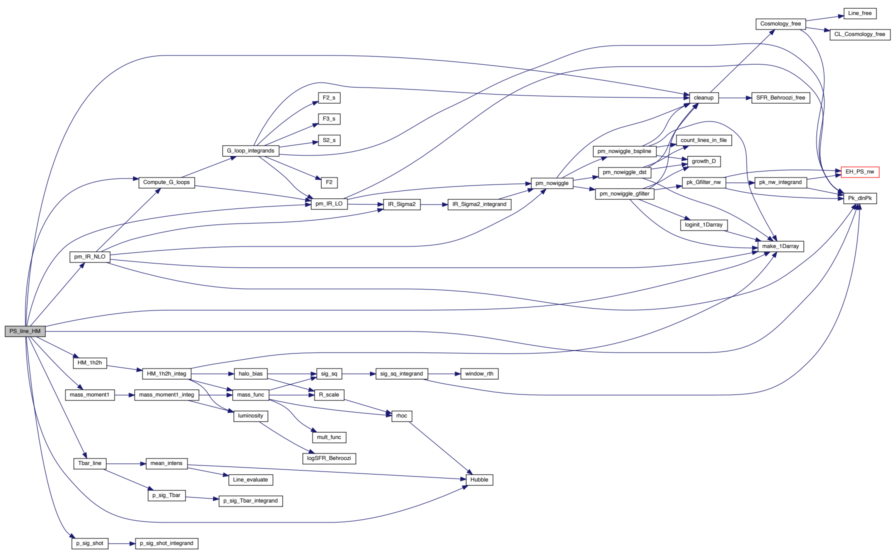
Boltzmann constant in unit of erg K^-1

in unit of erg/s

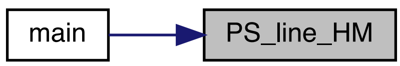
CII

to plot the power spectrum in units of micro K^2 Mpc^3

in unit of M_sun/Mpc^3Here is the call graph for this function:



Here is the caller graph for this function:



5.11.2.8 PS_shot_HM()

```
double PS_shot_HM (
        struct Cosmology * Cx,
        double k,
        double z,
        double M_min,
        double * input,
        long mode_mf,
        long line_type )
```

Compute the shot noise contributions, including corrections beyond poisson limit (see 1706.08738 for more details) If nfw=1, the dependance of the power spectrum on the halo profile is neglected.

Otherwise, NFW halo profile is assumed

Parameters

Cx	Input↩ : Cosmology structure
k	Input↩ : wavenumber in unit of 1/Mpc.
z	Input↩ : redshift
M_min	Input↩ : minimum halo mass for mass integrals
input	inpute↩ : an array of input values with 4 values, Tave↩ _line, b1↩ _line, pb22↩ _ls, line↩ _shot, rhom↩ _bar

Parameters

mode_mf	Inpute↩: theoretical model of halo mass function to use. It can be set to sheth-↩Tormen (ST), Tinker (TR) or Press-↩Schecter (PSC)
line_type	Inpute↩: name of the line to compute. It can be set to CII, CO10, CO21, CO32, CO43, CO54, CO65

Returns

P_stoch(k)

Boltzmann constant in unit of erg K^-1

in unit of erg/s

CII

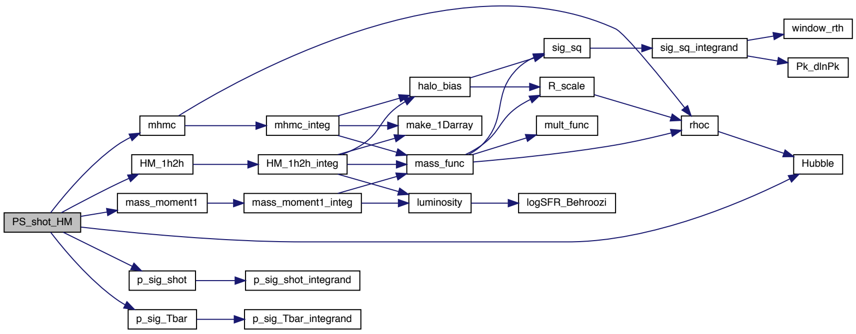
Since the following quantities do not depend on k, I am computing them once and pass them as input to this function

to plot the power spectrum in units of micro K^2 Mpc^3

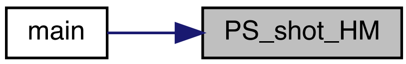
in unit of M_sun/Mpc^3

in unit of M_sun/Mpc^3

in unit of M_sun/Mpc^3Here is the call graph for this function:



Here is the caller graph for this function:



5.11.3 Variable Documentation

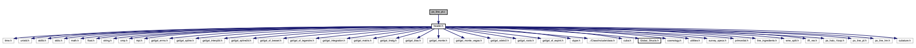
5.11.3.1 gb `struct globals gb`

5.12 ps_line_pt.c File Reference

Documented computation of Poisson shot noise and tree-level line power spectrum in real and redshift-space.

`#include "header.h"`

Include dependency graph for ps_line_pt.c:



Functions

- double PS_line (struct Cosmology ∗Cx, double k, double z, size_t line_id)

    Compute the real-space 3D power spectrum of emission lines in unit of micro K^2 Mpc^3.
- double PS_line_RSD (struct Cosmology ∗Cx, struct Cosmology ∗Cx_ref, double k, double mu, double z, size_t line_id)

    Compute the redshift-space 3D power spectrum of emission lines in unit of micro K^2 Mpc^3 as a function of wavenumber and angle w.r.t.
- int ps_line_multipoles_integrand (unsigned ndim, const double ∗x, void ∗p, unsigned fdim, double ∗fvalue)

    Compute the multipole moments of redshift-space power spectrum of emission lines in unit of micro K^2 Mpc^3, integrating over the angle w.r.t LOS, weighted by.
- double ps_line_multipoles (struct Cosmology ∗Cx, struct Cosmology ∗Cx_ref, double k, double z, size_↩t line_id, int ell)
- double PS_shot (struct Cosmology ∗Cx, double z, size_t line_id)

    Compute the Poisson shot noise in unit of micro K^2 Mpc^3.

Variables

- struct globals gb

5.12.1 Detailed Description

Documented computation of Poisson shot noise and tree-level line power spectrum in real and redshift-space.

Azadeh Moradinezhad Dizgah, November 4th 2021

NOTE TODO: Add the 1loop redshift-space power spectrum of the line. This requires implementing FFTLog, still in progress For the moment we stick to the tree-level expression of line power spectrum in redshift-space.

In summary, the following functions can be called from other modules:

1. PS_line() computes tree-level line power spectrum in real-space
2. PS_line_RSD() computes the tree-level line power spectrum in redshift-space, as a function of wavenumber and angle w.r.t LOS
3. ps_line_multipoles() computes the redshift-space multipoles of the line power spectrum
4. PS_shot() computes the poisson shot noise

5.12.2 Function Documentation

5.12.2.1 PS_line()

```
double PS_line (
        struct Cosmology * Cx,
        double k,
        double z,
        size_t line_id )
```

Compute the real-space 3D power spectrum of emission lines in unit of micro K^2 Mpc^3.

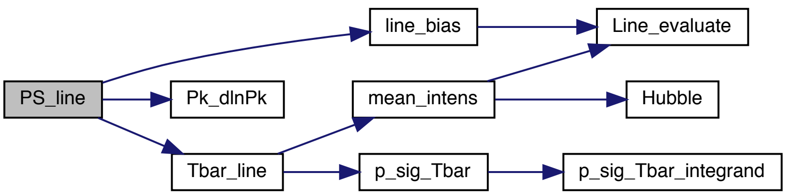
Parameters

Cx	Input↩ : Cosmology structure
k	Input↩ : wavenumber in unit of 1/Mpc.
z	Input↩ : redshift
line_id	Inpute↩ : id of the line to be considered.

Returns

tree-level P_clust(k)

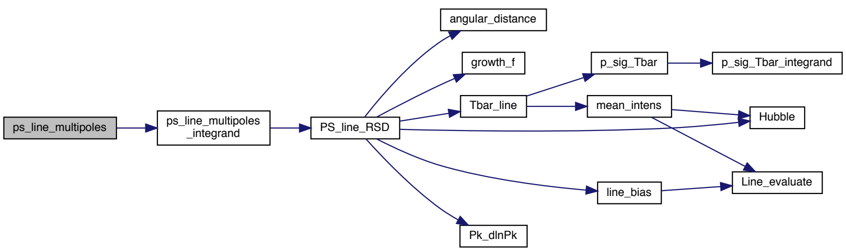
Here is the call graph for this function:



5.12.2.2 ps_line_multipoles()

```
double ps_line_multipoles (
    struct Cosmology * Cx,
    struct Cosmology * Cx_ref,
    double k,
    double z,
    size_t line_id,
    int ell )
```

Here is the call graph for this function:



5.12.2.3 ps_line_multipoles_integrand()

```
int ps_line_multipoles_integrand (
    unsigned ndim,
    const double * x,
    void * p,
    unsigned fdim,
    double * fvalue )
```

Compute the multipole moments of redshift-space power spectrum of emission lines in unit of micro K^2 Mpc^3, integrating over the angle w.r.t LOS, weighted by.

Parameters

Cx	Input: Cosmology structure
Cx_ref	Input: Reference cosmology structure, needed for AP effect
k	Input: wavenumber in unit of 1/Mpc.
z	Input: redshift

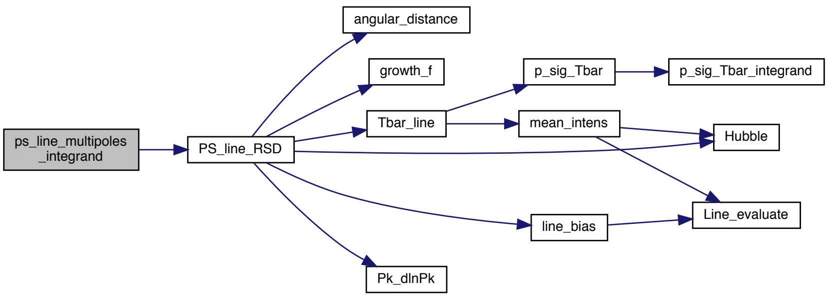
Parameters

line_id	Inpute↩ : id of the line to be considered.
ell	Inpute↩ : the multipole

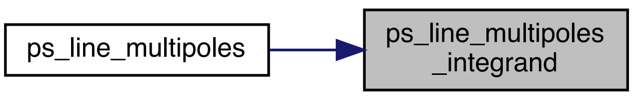
Returns

P_ell(k)

Here is the call graph for this function:



Here is the caller graph for this function:



5.12.2.4 PS_line_RSD()

```
double PS_line_RSD (
        struct Cosmology * Cx,
        struct Cosmology * Cx_ref,
        double k,
        double mu,
        double z,
        size_t line_id )
```

Compute the redshift-space 3D power spectrum of emission lines in unit of micro K^2 Mpc^3 as a function of wavenumber and angle w.r.t.

LOS

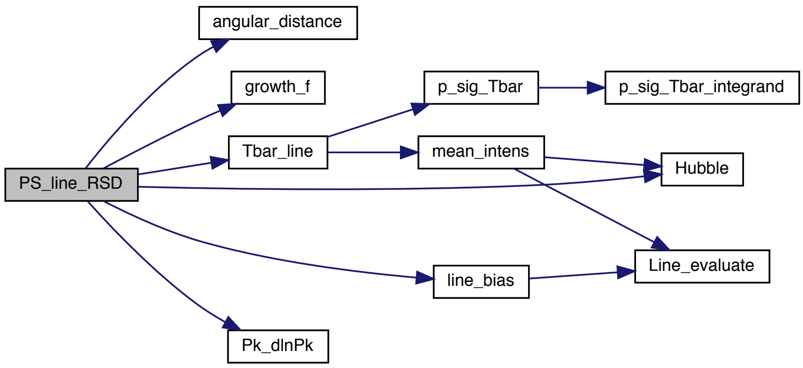
Parameters

Cx	Input : Cosmology structure
Cx_ref	Input : Reference cosmology structure, needed for AP effect
k	Input : wavenumber in unit of 1/Mpc.
mu	Inpute : angle w.r.t LOS
z	Input : redshift
line_id	Inpute : id of the line to be considered.

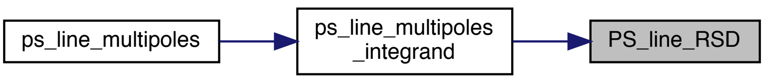
Returns

tree-level P_clust(k,mu)

to plot the power spectrum in units of micro K^2 Mpc^3Here is the call graph for this function:



Here is the caller graph for this function:



5.12.2.5 PS_shot()

```
double PS_shot (
        struct Cosmology * Cx,
        double z,
        size_t line_id )
```

Compute the Poisson shot noise in unit of micro K^2 Mpc^3.

Parameters

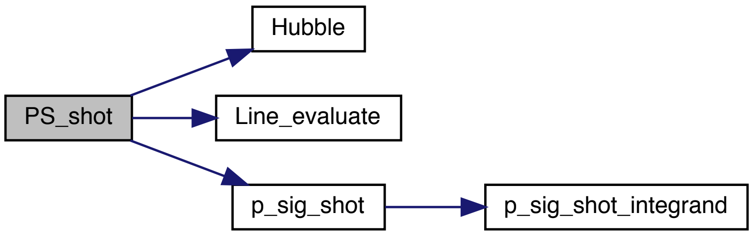
Cx	Input : Cosmology structure
z	Input : redshift
line_id	Inpute : id of the line to be considered

Returns

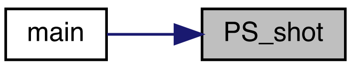
P_poisson
in unit of micro K^2 Mpc^3

Boltzmann constant in unit of erg K^-1

in unit of erg/sHere is the call graph for this function:



Here is the caller graph for this function:



5.12.3 Variable Documentation

5.12.3.1 gb `struct globals gb`

5.13 survey_specs.c File Reference

Documented computation of some survey-related functions.

`#include "header.h"`
Include dependency graph for survey_specs.c:

Functions

- double shell_volume (struct Cosmology *Cx, double z, double fsky)

    Compute the comoving volume of a survey covering redshift up to z.
- double kmin_val (struct Cosmology *Cx, double zmin, double zmax, double fsky)

    Compute the size of fundumental mode corresponding to the comoving volume enclosed in a redshift bin [zmin,zmax].
- double kmax_Brent (double kmax, void *params)

    Compute the maximum k-value used in Fisher forecast at each redshift bin.
- double kmax_Brent_solver (struct Cosmology *Cx, double z)

Variables

- struct globals gb

5.13.1 Detailed Description

Documented computation of some survey-related functions.

Azadeh Moradinezhad Dizgah, November 4th 2021

In summary, the following functions can be called from other modules:

1. shell_volume() computes the comoving volume of a survey covering redshift up to z
2. kmin_val() computes the fundumental k-mode of a given redshift shell
3. kmax_Brent_solver() computes the kmax value such that kmax(z=0) = 0.15 h/Mpc

5.13.2 Function Documentation

5.13.2.1 kmax_Brent()

```
double kmax_Brent (
    double kmax,
    void * params )
```

Compute the maximum k-value used in Fisher forecast at each redshift bin.

We follow Giannantonio et al. to for determining kmax, and use gsl Brent solver to solve for kmax in each redshift bin. The goal is to compute the kmax such that at z=0, the variance of the matter fluctations has a fixed value, for instance 0,36. This can be achieved by solving Eq. 40 of Giannantonio: sigma^2(z) = int_kmin^kmax(z) dk k^2/(2pi^2) P_m(k,z) = 0.36. Instead of fixing sigma^2 to 0.36, I chose the variance such that kmax(z=0) = 0.15 h/Mpc. This corresponds to the variance of ∼0.33 at z=0 . In the forecast, I additionally always impose kmax<0.3 h/Mpc cut.

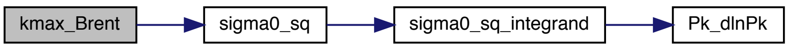
Parameters

Cx	Input↔ : Cosmology structure
z	Input↔ : redshift of interest

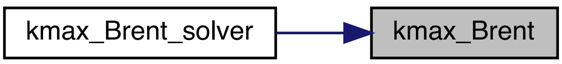
Returns

kmax

Here is the call graph for this function:



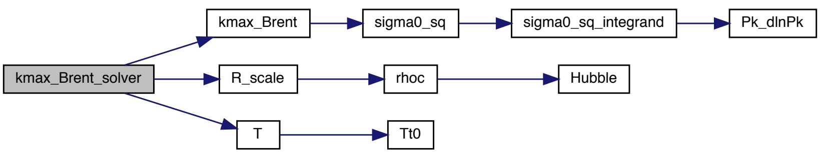
Here is the caller graph for this function:



5.13.2.2 kmax_Brent_solver()

```
double kmax_Brent_solver (
    struct Cosmology * Cx,
    double z )
```

in short paper we used, 3.631872e-01 ;
Here is the call graph for this function:



5.13.2.3 kmin_val()

```
double kmin_val (
        struct Cosmology * Cx,
        double zmin,
        double zmax,
        double fsky )
```

Compute the size of fundumental mode corresponding to the comoving volume enclosed in a redshift bin [zmin,zmax].

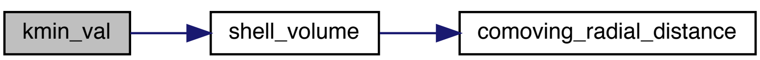
Parameters

Cx	Input : Cosmology structure
zmin	Input : minimum redshift
zmin	Input : maximum redshift
fsky	Input : sky-coverage of teh survey

Returns

kmin

Here is the call graph for this function:



5.13.2.4 shell_volume() double shell_volume (

```
struct Cosmology * Cx,
double z,
double fsky )
```

Compute the comoving volume of a survey covering redshift up to z.

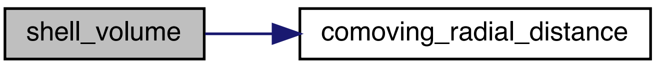
Parameters

Cx	Input↩ : Cosmology structure
z	Input↩ : redshift
fsky	Input↩ : sky-coverage of teh survey

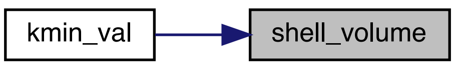
Returns

the comoving z-shell volume

Here is the call graph for this function:



Here is the caller graph for this function:



5.13.3 Variable Documentation

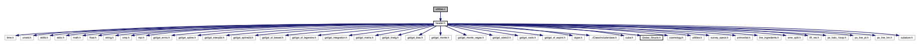
5.13.3.1 gb `struct globals gb`

5.14 utilities.c File Reference

Documented basic utility functions used by other modules of the code.

```
#include "header.h"
```

Include dependency graph for utilities.c:



Functions

- double ∗ make_1Darray (long size)

  Allocate memory to a 1d array of type double and length size.
- int ∗ make_1D_int_array (long size)

  Allocate memory to a 1d array of type integer and length size.
- double ∗∗ make_2Darray (long nrows, long ncolumns)

  Allocate memory to a 2d array of type double.
- void free_2Darray (double ∗∗m)

  Free the memory allocated to a 2d array.
- double ∗ init_1Darray (long n, double xmin, double xmax)

  initialize a 1d array, with values in the range of [xmin,xmax] and evenely-space on linear scale
- double ∗ loginit_1Darray (long n, double xmin, double xmax)

  initialize a 1d array, with values in the range of [xmin,xmax] and evenely-space on natural-log scale
- double ∗ log10init_1Darray (long n, double inc, double xmin)

  initialize a 1d array, with values in the range of [xmin,xmax] and evenely-space on log10 scale
- long count_lines_in_file (char ∗fname)

  Count the number of lines of a file.
- long count_cols_in_file (char ∗fname)

  Count the number of columns of a file.

5.14.1 Detailed Description

Documented basic utility functions used by other modules of the code.

Azadeh Moradinezhad Dizgah, November 4th 2021

In summary, the following functions can be called from other modules:

1. make_1Darray() dynamically allocates memory to a 1d array
2. make_2Darray() dynamically allocates memory to a 2d array
3. free_2Darray() free the memory allocated to a 2d array
4. init_1Darray() initialize a 1d array with linear spacing
5. loginit_1Darray() initialize a 1d array with natural-log spacing
6. log10init_1Darray() initialize a 1d array with log10 spacing
7. count_lines_in_file() count the number of lines of a file
8. count_cols_in_file() count number of columns of a file
9. return_arr()

5.14.2 Function Documentation

5.14.2.1 count_cols_in_file()

```
long count_cols_in_file (
    char * fname )
```

Count the number of columns of a file.

Parameters

fname	Input↔ : file-name

Returns

long integer value of ncols

5.14.2.2 count_lines_in_file()

```
long count_lines_in_file (
    char * fname )
```

Count the number of lines of a file.

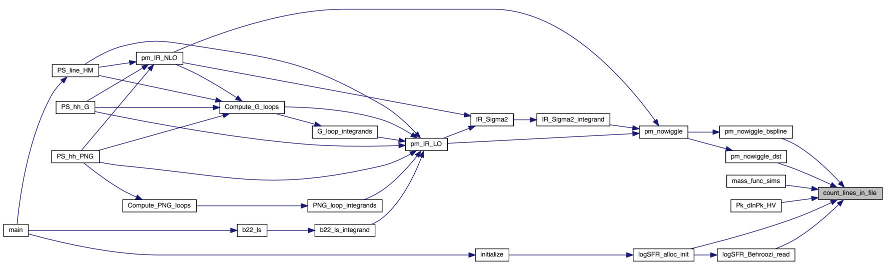
Parameters

fname	Input↔ : file-name

Returns

long integer value of nlines

Here is the caller graph for this function:



5.14.2.3 free_2Darray() `void free_2Darray ( double ** m )`

Free the memory allocated to a 2d array.

Parameters

m	Input← : double pointer to the elements of 2d array

Returns

void

5.14.2.4 init_1Darray() `double * init_1Darray ( long n, double xmin, double xmax )`

initialize a 1d array, with values in the range of [xmin,xmax] and evenely-space on linear scale

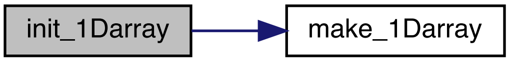
Parameters

n	Input← : number of elements
xmin	Input← : start point
xmiax	Input← : end point

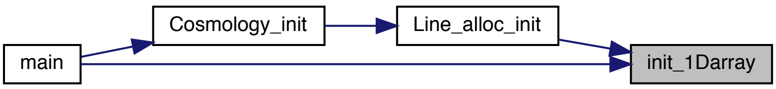
Returns

a pointer to a double type 1d array, with values initialized

Here is the call graph for this function:



Here is the caller graph for this function:



5.14.2.5 log10init_1Darray()

```
double * log10init_1Darray (
    long n,
    double inc,
    double xmin )
```

initialize a 1d array, with values in the range of [xmin,xmax] and evenely-space on log10 scale

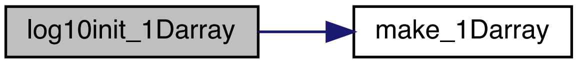
Parameters

n	Input←: number of elements
xmin	Input←: start point
xmiax	Input←: end point

Returns

a pointer to a double type 1d array, with values initialized

Here is the call graph for this function:



5.14.2.6 loginit_1Darray()

```
double * loginit_1Darray (
        long n,
        double xmin,
        double xmax )
```

initialize a 1d array, with values in the range of [xmin,xmax] and evenely-space on natural-log scale

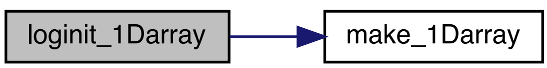
Parameters

n	Input : number of elements
xmin	Input : start point
xmiax	Input : end point

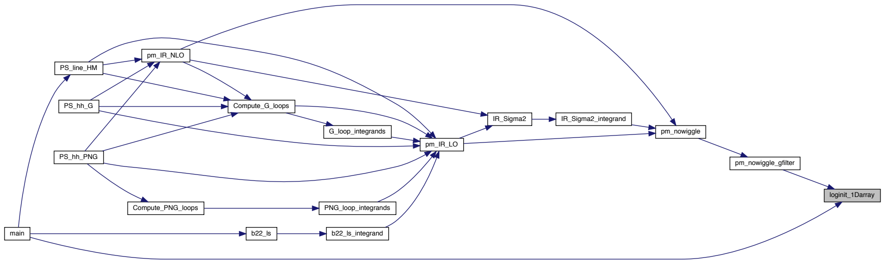
Returns

a pointer to a double type 1d array, with values initialized

Here is the call graph for this function:



Here is the caller graph for this function:



5.14.2.7 make_1D_int_array() `int * make_1D_int_array ( long size )`

Allocate memory to a 1d array of type integer and length size.

Parameters

size	Input↩ : length of the arrat

Returns

a pointer to an integer type 1d array

5.14.2.8 make_1Darray() `double * make_1Darray ( long size )`

Allocate memory to a 1d array of type double and length size.

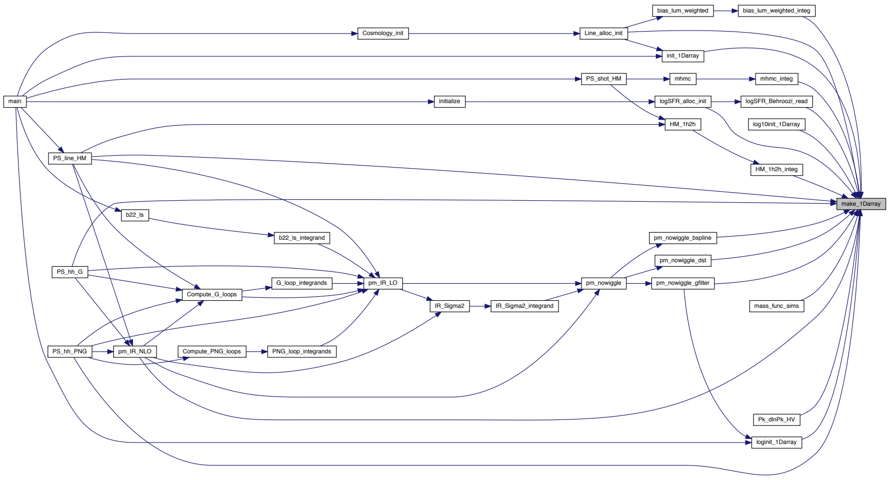
Parameters

size	Input↩ : length of the array

Returns

a pointer to a 1d array

Here is the caller graph for this function:



5.14.2.9 make_2Darray()

```
double ** make_2Darray (
        long nrows,
        long ncolumns )
```

Allocate memory to a 2d array of type double.

Parameters

nrows	Input← : number of rows of the output array
ncols	Input← : number of columns of the output array

Returns

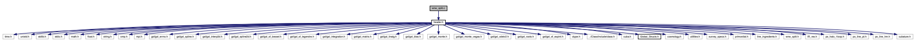
a double pointer to a double type 2d array

5.15 wnw_split.c File Reference

Documented wiggle-nowiggle split based on 3d Gaussian filter in linear k, and using the Eisentein-Hu wiggle-no wiggle template

```
#include "header.h"
```

Include dependency graph for wnw_split.c:



Functions

- double pk_Gfilter_nw (struct Cosmology ∗Cx, double k, double k0)

  Compute the nowiggle component of linear matter power spectrum using 3d Gaussian filter Computing the nowiggle component involves calculating an integral (Eq.
- double pk_nw_integrand (double x, void ∗par)

  Integrand to compute the nowiggle matter power spectrum.
- double EH_PS_w (struct Cosmology ∗Cx, double k, double k0, double pk0)

  Compute the Eisentein-Hu approximate wiggle component of linear matter power spectrum.
- double EH_PS_nw (struct Cosmology ∗Cx, double k, double k0, double pk0)

  Compute the Eisentein-Hu approximate nowiggle component of linear matter power spectrum.
- double T0 (struct Cosmology ∗Cx, double k)

  Compute ????? AM:EDIT.
- double T (struct Cosmology ∗Cx, double k)

  Compute the total baryon+CDM transfer function.
- double Tt0 (struct Cosmology ∗Cx, double k, double x1, double x2)

  Compute ????? AM:EDIT.

5.15.1 Detailed Description

Documented wiggle-nowiggle split based on 3d Gaussian filter in linear k, and using the Eisentein-Hu wiggle-no wiggle template

Azadeh Moradinezhad Dizgah, June 16th 2021

The algorithm closely follows Ref. arXiv:1509.02120 by Vlah et al. (described in Appendix A)

The following function will be called from other modules:

1. pk_Gfilter_nw()

5.15.2 Function Documentation

5.15.2.1 EH_PS_nw()

```
double EH_PS_nw (
        struct Cosmology * Cx,
        double k,
        double k0,
        double pk0 )
```

Compute the Eisentein-Hu approximate nowiggle component of linear matter power spectrum.

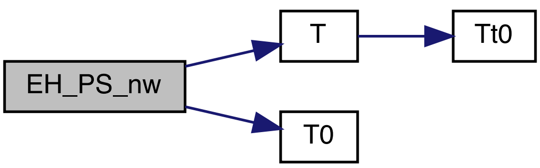
Parameters

Cx	Input← : pointer to Cosmology structure
k	Input← : wavenumber in unit of 1/Mpc
k0	Input← : smallest value of k, i.e. the largest scale
pk0	Input← : value of the power spectrum at the largest scale

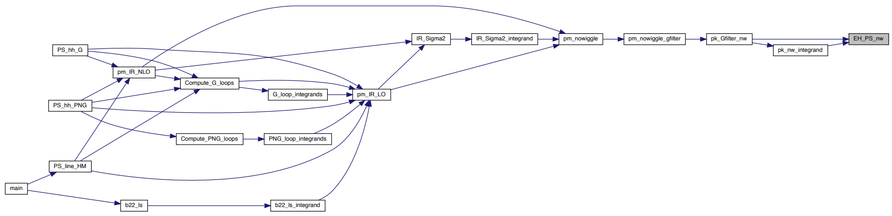
Returns

P_nw(k) in unit of (Mpc)^3

Here is the call graph for this function:



Here is the caller graph for this function:



5.15.2.2 EH_PS_w()

```
double EH_PS_w (
    struct Cosmology * Cx,
    double k,
    double k0,
    double pk0 )
```

Compute the Eisentein-Hu approximate wiggle component of linear matter power spectrum.

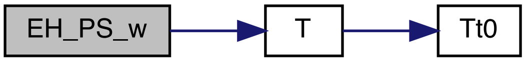
Parameters

Cx	Input: pointer to Cosmology structure
k	Input: wavenumber in unit of 1/Mpc
k0	Input: smallest value of k, i.e. the largest scale
pk0	Input: value of the power spectrum at the largest scale

Returns

P_w(k) in unit of (Mpc)^3

Here is the call graph for this function:



5.15.2.3 pk_Gfilter_nw()

```
double pk_Gfilter_nw (
    struct Cosmology * Cx,
    double k,
    double k0 )
```

Compute the nowiggle component of linear matter power spectrum using 3d Gaussian filter Computing the nowiggle component involves calculating an integral (Eq.

A3 of Vlah et al) Below, pk_nw_integrand()is the corresponding integrand and pk_Gfilter_nw() is the integrator

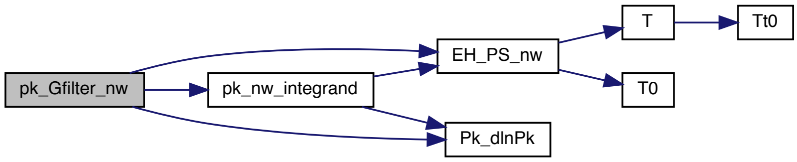
Parameters

Cx	Input : pointer to Cosmology structure
k	Input : wavenumber in unit of 1/Mpc
k0	Input : smallest value of k, i.e. the largest scale

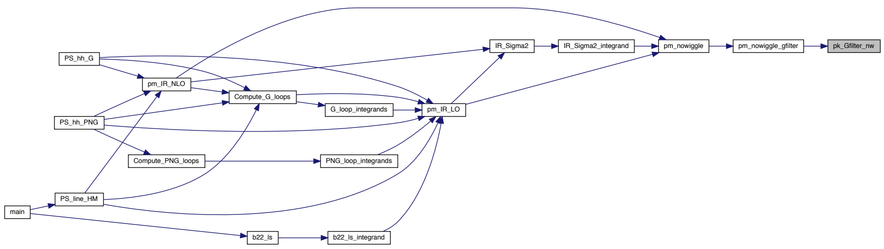
Returns

broadband component in unit of (Mpc)^3

Here is the call graph for this function:



Here is the caller graph for this function:



5.15.2.4 pk_nw_integrand()

```
double pk_nw_integrand (
    double x,
    void * par )
```

Integrand to compute the nowiggle matter power spectrum.

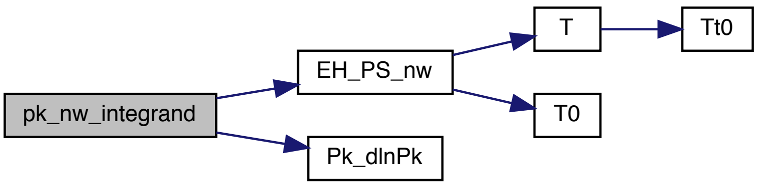
Parameters

x	Input: integration variable, k-values
par	Input: integration parameters

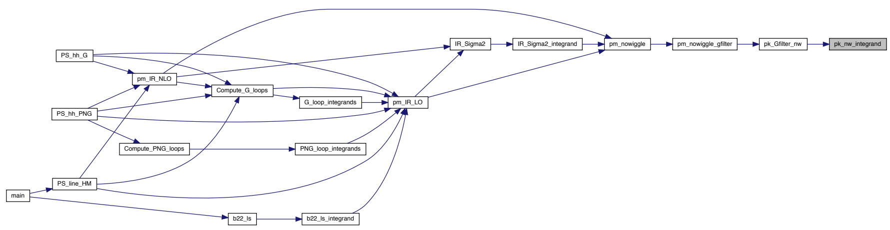
Returns

integrand to be used in pk_Gfilter_nw() function
integration variable x = logq

Here is the call graph for this function:



Here is the caller graph for this function:



5.15.2.5 T()

```
double T (
    struct Cosmology * Cx,
    double k )
```

Compute the total baryon+CDM transfer function.

Parameters

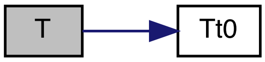
k	Input: wavenumber in unit of 1/Mpc

Returns

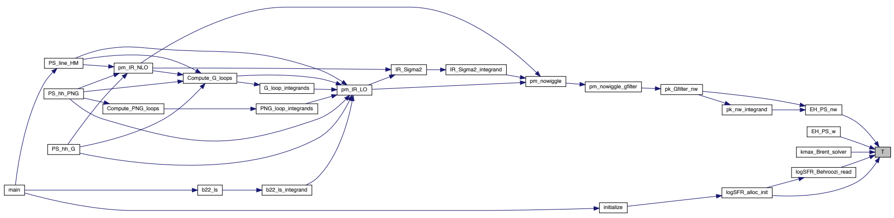
value of baryon+cdm transfer function

H0 value devided by the speed of light

approximate sound speed given in Eq. (26) of EHHere is the call graph for this function:



Here is the caller graph for this function:



5.15.2.6 T0()

```
double T0 (
    struct Cosmology * Cx,
    double k )
```

Compute ????? AM:EDIT.

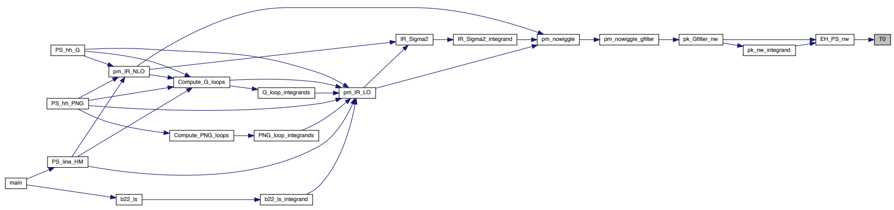
Parameters

k	Input← : wavenum- ber in unit of 1/Mpc

Returns

value of ???

approximate sound speed given in Eq. (26) of EHHere is the caller graph for this function:



5.15.2.7 Tt0()

```
double Tt0 (
    struct Cosmology * Cx,
    double k,
    double x1,
    double x2 )
```

Compute ????? AM:EDIT.

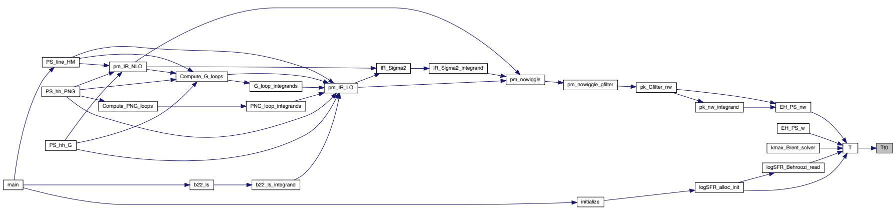
Parameters

Cx	Input : pointer to Cosmology structure
k	Input : wavenumber in unit of 1/Mpc.
x1	Input : betac AM :WHAT WAS THIS VARIABLE???
x2	Input : betac AM :WHAT WAS THIS VARIABLE???

Returns

value of ???? x1 = alphac, x2 = betac

Here is the caller graph for this function:



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